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Forest Health and Productivity in a Changing Atmospheric Environment

A Priority Research Program

FOREST PRODUCTIVITY AND HEALTH IN A CHANGING ATMOSPHERIC ENVIRONMENT

CONCEPTUAL PLAN

for the

FOREST/ATMOSPHERE INTERACTION PRIORITY RESEARCH PROGRAM

Forest Fire and Atmospheric Sciences Research Staff

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EXECUTIVE SUMMARY

Anticipated changes in the physical and chemical nature of the Earth's climate are likely to have a significant impact on the Nation's forests and related ecosystems. These changes will require the U.S. Forest Service (USFS) and other land managers to respond with effective management practices to protect and maintain forest health and productivity. The development of new management techniques, however, is limited by the current lack of sufficient information on the current state of U.S. forests and by an inability to predict and detect changes in forest health and productivity due to climate change.

The Forest/Atmosphere Interaction Priority Research Program (FAI-PRP) is being initiated to build upon existing research efforts and to use a complete ecosystem perspective when examining the interactions between forests and the atmosphere. The objective of the FAI-PRP is to provide the scientific basis to address three broad questions on the effects of physical and chemical climate change on forest, range, and related ecosystems:

- What processes in forested ecosystems are sensitive to physical and chemical changes in the atmosphere?
- How will future physical and chemical climate changes influence the structure, function, and productivity of forests and related ecosystems?
- What are the implications for forest management and how must forest management activities be altered to sustain forest health and productivity?

Program Research Elements

Two planning workshops during 1987-88 have produced a set of research elements upon which to focus the resources of the FAI-PRP. These elements fall under four general categories: (1) effects of the atmosphere on ecosystems; (2) effects of ecosystem changes on the atmosphere; (3) assessment of long-term changes; and (4) ecosystem modeling.

Effects of the Atmosphere on Ecosystems

1. *Energy, Carbon, Water, and Nutrient Cycling* - Determine the simultaneous responses of energy, carbon, water, and nutrient cycles with altered physical and chemical atmospheric conditions.

2. *Species Life Histories and Distributions and Community Compositions* - Develop methods to predict changes in species life histories and distributions, and community composition and distribution resulting from global climate change.

3. *Water Yields, Erosion, and Sedimentation* - Develop methods to predict changes in water yields, erosion, and sedimentation in forest and rangelands resulting from climate change.

4. *Fire Severity and Occurrence* - Develop methods to predict changes in fire severity and occurrence resulting from global climate change.

5. *Aquatic Ecosystems and Fisheries* - Determine the response of aquatic ecosystems and fisheries to changes in the physical and chemical environment.

6. *Wildlife and Domestic Species* - Determine the sensitivity to and impact on wildlife and domestic species from changes in the physical environment and climate change.

7. *Microbes, Plant Pathogens and Insects* - Determine the sensitivity to and impact on microbe populations and microbe- produced products, plant pathogens, and insects to changes in the physical and chemical atmosphere.

8. *Quantity and Quality of Wood* - Determine the effects of altered physical and chemical climate on the quantity and quality of wood.

9. *Mass, Energy and Momentum Transfer* - Develop an understanding of mass, energy,

and momentum transfer between forests and the atmosphere.

Effects of Ecosystem Change on the Atmosphere

10. *Emissions of Forests and Forest Fires* - Refine estimates and mechanisms of emissions from forests and related ecosystems.

11. *Transport and Dispersion of Forest Pollutants* - Improve understanding of transport and dispersion of pollutants associated with prescribed fire and wildfire.

12. *Changes in Forest Area* - Determine effects of large changes in forest area (including fire) on energy, carbon, oxygen, water budgets and on composition of the atmosphere.

Assessment of Long-Term Changes

13. *Long-Term Ecosystem Monitoring* - The USFS has defined monitoring as the long-term, periodic measurement of selected physical and biological parameters for establishing base lines and to detect and quantify change over time. This plan will institute and use long-term ecosystem monitoring, particularly building on existing Experimental Forests, Experimental Rangelands, and Research Natural Areas to accomplish the following:

(a) determine long-term trends in forest condition, rangelands and related ecosystems;

(b) determine the extent and magnitude of current forest condition in relation to natural and anthropogenic stresses;

(c) identify critical variables necessary to assess ecosystems response to changes in physical and chemical climates, and develop methods to monitor these variables on a wide basis, including monitoring within Forest Plans;

(d) identify ecological, physiological, and/or morphological characteristics that can serve as indicators of chemical and-or physical environmental changes; and

(e) verify model-based predictions of changing forest condition in relation to a changing environment.

Ecosystem Modeling

14. *Ecosystem Management Models* - Develop and/or adapt ecosystem models relevant to managing forests and related ecosystems.

15. *Spatial and Temporal Scale Interfaces* - Develop techniques to improve interfaces between models at differing spatial and temporal scales.

16. *Interfaces between Ecological and Management Models* - Develop methods of interfacing ecosystem simulation models with management-oriented models.

Expected Outputs

Results from each of the research elements listed above will provide the scientific knowledge required to address management issues under a changed physical and chemical climate. New information will enable resource managers to do the following:

- Determine the changes in species distribution and forest composition resulting from air pollution and climate change effects;

- Predict growth and yield of commercial tree species, and as a result, future timber supply under a changing physical and chemical climate;

- Predict the quality of forest products and therefore their economic value under a changed climate;

- Predict changes in habitat and carrying capacity of rangelands for game, non-game, and managed animals as a result of climate change;

- Predict future water supply and quality in a changed physical and chemical climate;
- Predict changes in sediment load in water courses resulting from climate change;
- Predict changes in habitat for endangered species as a result of climate change;
- Predict changes in recreational opportunities, particularly in wilderness as a result of climate change.
- Predict the changes in fire frequency and severity and therefore be able to estimate the future protection required; and
- Predict the changes in severity and intensity of insect and disease outbreaks resulting from physical and chemical climate change.

Research Categories

The research elements were assigned first, second, and third categories based on the need to meet the future forest management as perceived by the USFS participants. The first category is that of fundamental science necessary to address the second and third categories. The basic minimum level program includes elements from all three categories.

First - The three first category elements involve research that addresses USFS mission statements and critical needs for resource management. The issues included apply across the entire program rather than individual resource categories.

1. Energy, Carbon, Water, and Nutrient Cycling

#13. Long-Term Ecosystem Monitoring

#14. Ecosystem Management Models

Second - The three second category elements include research that addresses the current issues of concern more specifically but still focus on basic research questions.

2. Species Life Histories and Distributions and Community Composition

3. Water Yields, Erosion, and Sedimentation

#12. Changes in Forest Area

Third - The remaining third category elements focus on specific ecosystem effects and additional research support activities. These elements involve a more regional and station-level perspective.

4. (Fire Severity and Occurrence)

5. Aquatic Ecosystems and Fisheries

6. Domestic and Wildlife Species

7. Microbes, Plant Pathogens, and Insects

8. Quantity and Quality of Wood

9. Mass, Energy, and Momentum Transfer

#10. Emissions of Forests and Forest Fires

#11. Transparent and Dispersion of Forest Pollutants

#15. Spatial and Temporal Scale Interfaces

#16. Simulation and Management Model Interfaces

Planning and Management Goals

During the planning and development of the FAI-PRP, the current set of goals, consistent with mandated goals of the USFS, can be used as a framework:

(1) Provide long-term technical input to policy questions.

(2) Maintain productivity of USFS lands, commercial forest lands, wildlands, and non-industrial private forest lands.

(3) Provide international forestry leadership in addressing forest/atmosphere interaction problems.

(4) Determine the nature and magnitude of climate-induced forest changes.

(5) Provide methods for detection of changes in forests and for determination of causality.

(6) Develop an information base to allow evaluation of future options.

(7) Provide information for forest and related land management plans.

(8) Determine the important climatic variables in forests and related ecosystems.

Program Budget, Resources, and Management

The budget development for the PRP will follow the usual USFS research budget process.

The current budget assumes a base level of $13 million with two additional increments of $8 million and $9 million to reach program totals of $21 million and $30 million, respectively.

Over the next five years, the USFS will experience about 50 percent turnover in personnel, and about 70 percent turnover during the next ten years. Given the nature and duration of the FAI-PRP, the workshop group recommended areas of expertise for future USFS personnel.

The organization of the research program will be consistent with USFS policies for (1) planned and approved research programs and (2) development of research organization and facilities. A continuation of decentralized management approach is recommended, where the Deputy Chief for Research provides national coordination and planning, and the Station Directors are responsible for administering the research programs. Management assistance would be provided by an advisory and steering committee.

PREFACE

The Forest/Atmospheric Interactions (FAI) Priority Research Program (PRP) will begin in FY 1990. This report is part of the program planning process required for the implementation of the program, and for a phased, orderly transition from the Forest Response Program (FRP) to the FAI-PRP. The material in this report is the product of a 3-day workshop held in Annapolis, MD, on April 4-6, 1988 (see Appendix A for a list of participants). The workshop and this report are a continuation of the process initiated at a preliminary planning workshop held in Reston, VA in March 1987. The report from the Reston workshop provided an information base from which to refine and further expand planning details.

The objective of the Forest/Atmosphere Interactions Priority Research Program is to provide scientific information to address three broad questions on the effects of physical and chemical climate changes on forest, range and related ecosystems.

(1) What processes in forested ecosystems are sensitive to physical and chemical changes in the atmosphere?

(2) How will future physical and chemical climate change influence the structure, function, and productivity of forest and range ecosystems?

(3) What are the implications for forest management, and how must forest management activities be altered to sustain forest health and productivity?

The specific objectives of the Annapolis workshop were the following:

(1) Establish priorities for the elements of the research program. The Reston Workshop (3/87) provided general guidance, but the final priority list was not limited to the ideas developed in Reston.

(2) Document the rationale for inclusion or exclusion of the program elements identified in the Reston Workshop.

(3) Establish a schedule of research problem implementation consistent with program scientific needs and funds made available from the Forest Response Program.

(4) Identify existing strengths and weaknesses in the human resources needed to fully address the FAI problems. Specifically, how well do our existing skills address the scientific needs and the proposed schedule, and where will we need to recruit or contract skills.

(5) Develop a recommendation or set of alternatives on program management that will assure coordination and budget tracking at the station, national, and external reporting levels.

The outputs of the Reston workshop included a list of 21 specific research problems, under four broad areas, that were identified as areas for priority research activity (see Appendix B). These specific problems were examined and modified as needed by the Annapolis group. The group then identified key scientific issues and potential research objectives. The research elements also were divided into first, second, and third categories. In addition, recommendations were made for budget, future staff, and organization needs.

INTRODUCTION

Climatic change and variability, along with stresses from existing and new atmospheric pollutants will have an, as yet, undetermined impact on forests and related ecosystems. In addition, the effect of climatic change on present pollutant exposure regimes is unknown. Resulting changes will require land managers to respond with innovative and effective management practices. The development of new management techniques, however, is limited by our lack of sufficient information on the current state of health of U.S. forests and our ability to predict and detect changes in forest health and productivity. In a changing physical and chemical environment, existing historical data are inadequate for predicting future forest responses.

The nation's forests and related ecosystems, including rangelands, wildlands, and other natural terrestrial ecosystems, represent an enormous natural and economic resource. *1/* Impacts of human activities, including impacts on the atmosphere, have the potential to create subtle but wide-ranging changes within forested ecosystems. Fundamental changes in community compositions and species distributions may also occur. Evidence is mounting that atmospheric pollutants, such as ozone in present concentrations, have altered productivity and possibly the species composition of forests. Concern is increasing that anthropogenic emissions of carbon dioxide and other radiatively active gases may dramatically alter global climate within the next century. Temperature and precipitation patterns will be altered by these greenhouse gases. Further, these physical climate changes will be superimposed on existing pollutant stresses. Consequently, entire landscapes may be altered and forest types shifted along altitudinal or latitudinal boundaries due to changes in climate.

Changes in regional precipitation patterns as well as increased temperatures will be associated with changes in global climate temperature. Possible increases in climatic variability may alter the frequencies of drought and flood. Climatic changes may also contribute to increased insect activity and disease incidence. Climatic shifts may surpass the rate at which vegetation migrates and soils evolve, resulting in highly stressed ecosystems. Alternatively, a decrease in the stratospheric ozone layer may prove to be more harmful to insects and disease and thus improve forest health and productivity, and increased carbon dioxide levels may increase growth in the short term.

Unexplained diebacks and declines in growth of forest stands are occurring in some areas. Air pollutants are suspected to be one of the causal agents, but causality has not been demonstrated yet, due to the complexity of forested ecosystems and the difficulty of linking data on forests and air pollutants with information from existing data bases. Closely coordinated, long-term monitoring of forests, air pollutants, and climate change must be implemented in order to detect changes in forest condition.

The Forest Response Program (FRP) of the National Acidic Precipitation Assessment Program (NAPAP) is a major interagency effort initiated specifically to investigate effects of acidic deposition and associated pollutants on forests and forest tree species. Invaluable experience and data have been produced through forest research cooperatives created to examine the potential effects of acidic deposition and associated pollutants on regional forest types. During the next two years, much of this information will be synthesized to assess the extent, magnitude, and nature of changes in these forest types and the contributing role of acid deposition in the cause of such changes.

1/ For remainder of document "forested ecosystems" implies "forest and related ecosystems." This includes fauna as well as flora, and also includes water resources and aquatic ecosystems.

There are advantages of building upon FRP research, which can be maximized if the evolution into a Forest/Atmosphere Interaction Priority Research Program is planned, designed, and developed carefully. Research programs initiated under FRP and similar programs (e.g. National Science Foundation Long-term Ecological Research) should be used as a research base to develop a broad-based and integrated program to monitor, assess, and protect forest ecosystems as integrated systems. The effects of global climate change cannot be detected or managed by focusing narrowly on one or two specific sources of effects or ecosystem receptors. Climatic change is one of a complex of multiple stress factors impacting forests; these factors require specific research designs and long-term efforts to detect the effects of a changing physical and chemical environment.

Focus of Research

The health of forests is determined by the status of vegetation, soils, water, and animal populations. Forest health or condition can be influenced by atmospheric pollutants. Forest productivity can be optimized by appropriate resource management and silvicultural practices that minimize disease, insects, and fire in order to increase growth.

The forests existing today have grown in and adapted to a physical and chemical climate very different from that which currently exists or what is expected to occur in the near future. An adequate management response has not been developed for factors that will determine future forest productivity, including *long-term climate change* and *increased climate variability* superimposed on *regional and global air pollution*. Strategic planning for the management and use of forest and water resources will depend on our ability to predict the effects of the physical and chemical climate on ecosystems.

In designing a priority research program for this emerging issue, the USFS acknowledges the importance of increasing our understanding of the interactions between all components of forested ecosystems and the atmosphere. The objective of the FAI-PRP is to provide the scientific basis to address three broad questions on the effects of physical and chemical climate change on forest, range, and related ecosystems:

(1) What processes in forested ecosystems are sensitive to physical and chemical changes in the atmosphere?

(2) How will future physical and chemical climate changes influence the structure, function, and productivity of forest and related ecosystems?

(3) What are the implications for forest management, and how must forest management activities be altered to sustain forest health and productivity?

A broad ecosystem viewpoint is essential when examining the multiple stresses impacting forest resources. The ecosystem viewpoint addresses a wide range of physical and chemical atmospheric variables as they interact to affect all components of forested ecosystems. Past efforts, by necessity, have focused on single stress factors. Future protection of forest resources depends on a long-term research effort committed to a broad-based understanding of natural dynamics and anthropogenic effects. The goal of the FAI-PRP is to supply forest ecosystem managers with the information they need to address changes associated with multiple-stress factors on forested ecosystems, especially those due to climatic change superimposed on existing pollutant stresses.

This priority research program, built on the base of USFS expertise gained in atmospheric deposition research, takes a complete ecosystem view of the interactions between forests and the atmospheric components that affect forest health and productivity. It will support long-term research, fundamental science and monitoring, and address effects of multiple pollutants and atmospheric change on key components of forested ecosystems.

Climate and Climatic Change

The atmosphere interacts with the biosphere in both physical and chemical ways. The physical climate system, namely the interactions of solar radiation, atmospheric dynamics, and the hydrologic cycle (gas, liquid, and ice), is coupled with biogeochemical cycles of nutrients (S, N, K, P, Mg, etc.) and carbon. Climatic change involves changes both in the physical climate system and in biogeochemical cycles, as well as possible changes in

pollutant exposure regimes; hence, we use the phrase physical and chemical climate. Changes in physical and chemical climates can be manifestations of natural processes, such as changes in insolation due to the Earth's orbital pattern or volcanic activity. However, anthropogenic activity also can cause major alterations. For example, temperature may increase due to elevated atmospheric concentrations of carbon dioxide and other greenhouse gases, or due to large-scale alterations in albedo caused by changing land uses.

The physical and chemical climate determine, to a large extent, the structure, function, and productivity of forests and related ecosystems. As a manager of these ecosystems, the USFS must anticipate the effects that alterations of the physical and chemical climate are likely to cause. These effects can be considered in a hierarchy of increasingly specific research questions that must be addressed. An example is the following:

How will forested ecosystems change in response to predicted changes in the physical and chemical climate? In order to answer this we need to know the following:

- The physical, chemical and biological processes that regulate forested ecosystems by exchanging energy, water, carbon, and nutrients with the atmosphere (ecosystem process research);

- The current status or condition of forested ecosystems with regard to their structure, function, stability and biogeochemical properties and changes in condition over time (monitoring); and

- The ways processes in forested ecosystems are likely to respond to changes in chemical and physical climates (modeling).

Survey and monitoring must be a first-priority consideration because of the insufficient data available on the current condition of these ecosystems and on rates of change in forest condition. Secondly, if the processes of ecosystem-atmosphere exchange can be understood, predictions of forested ecosystem response to various scenarios of chemical and physical climate change will be possible. Thus, developing a process-level understanding of forested ecosystems is another high priority.

Response to Global Climate Change versus "Natural" Variations

Many of the biological systems or processes that are expected to respond to changes in global climate also respond to many natural stress factors, often with similar results. For example, both drought and air pollutants may cause a reduction in photosynthesis and growth. Short-term cycles of climate and other natural stresses such as pests and pathogens can affect forest growth. The concern, however, is that changes in biological systems or processes caused by global climate change may be very small or subtle compared to seasonal or monthly changes caused by natural stress factors, e.g., a drought or a late spring frost, while over the longer term greater effects may be found. Thus, to understand completely the impact of global climate change on the biological system or process and to predict likely scenarios of forest response, the response of the system or process to natural stress factors must be understood and included in process-based models. Long-term monitoring and research also are required.

To understand how ecosystems will respond to global climate change, it will be necessary to understand how biological processes, species and community complexes within ecosystems respond to change. This is important because even if a process, such as photosynthesis, is affected in more than one species, the species impacts may differ in severity. A slight difference in impact between species may result in a change in competitive interactions.

Long-Term Research/Monitoring

Experience gained from the FRP strongly supports an extensive and intensive plot system to evaluate subtle changes in the atmospheric environment and responses to those changes over time and space. Measurements made need to be broadened to include complete descriptions of forest conditions and be expanded to the scale of small watersheds. The full value of and need for support of this kind of research cannot be overemphasized.

In conducting research on forest ecosystems where stand age can exceed 100 years and stand conditions are highly variable, atmospheric interactions and responses within a specific range of time and place will be impossible to document without a commitment to long-term (20-50 years) research. In the FRP, long-term studies (research/monitoring) have been established in eastern spruce-fir, southern commercial pines, eastern hardwoods, and western conifers. In addition, the National Vegetation Survey has developed methods to evaluate forest condition and to examine long-term Forest Inventory Analysis (FIA) data bases.

The long-term studies of the FRP will have generated only 4-5 years of continuous data by 1990, but these studies should be considered as a solid foundation for the FAI. When coupled with additional plots and small watersheds established in Experimental Forests and Rangelands and in Research Natural Areas, the USFS has outstanding capabilities to undertake long-term research and monitoring of forest/atmospheric interactions. A significant long-term commitment is required. Without a commitment for a minimum of 10 years or more, documenting the subtle changes in forest/atmospheric interactions that might take place will be extremely difficult.

Spatial and Temporal Scales

FAI research must be conducted over a range of spatial and temporal scales to attain an integrated understanding of the behavior of ecosystems in relation to physical and chemical changes in the environment. For many studies, an ecosystem unit the size of a small watershed will be necessary to examine inputs, outputs, and mediating processes that affect forest ecosystem behavior. This size is comparable to that of forest management units; forest plots can be located within small watersheds and a focus on ecosystems at this scale will facilitate the application of research results into management of such units. Many studies may occur at a much different spatial scale, however, ranging from forest landscapes that include composites of stands and networks of watersheds, to individual trees or portions of the soil-plant-atmosphere continuum. Similarly, research will be required over a range of temporal scales. While some forest-atmosphere responses may be addressed on an annual basis, other processes require study over periods as short as a day or an hour or as long as the life cycle of the organisms involved. The types of research required by this PRP require various spatial and temporal scales, and research approaches will depend upon the scales involved. Only by focusing on a variety of scales of time and space can the FAI detect the subtle ecosystem responses to climatic change.

Impacts on patterns and processes may be observable only at the landscape scale in response to climate changes. Patterns of climatic variables will shift in different directions. For example, precipitation patterns may shift 100 miles or more in response to changes in air mass tracks, but the transient snow zone may only shift a few hundred feet up slope in response to warmer winter temperatures (Neilson and Wullstein, 1983).

Landform and land use affect the structure of ecosystems (Franklin and Forman, 1987; Swanson et al., 1988). Changing climatic patterns will be superimposed on these existing landform and land use patterns. Species and communities will respond to the changing pattern. Plant species will shift ranges differently in response to changes in the pattern of the environment (Neilson, 1987); the same may be true of stream characteristics (e.g., low flows and peak flows) and erosion that is driven in part by the hydrologic cycle, vegetation, and land form patterns (Swanson et al., 1988). These pattern shifts may affect riparian and aquatic ecosystems at the same scale. Domestic and wild animal species will sense these changes in patterns of physical and vegetative habitat. Studies of their responses must be at the appropriate scales. Changes in patterns of fuel moisture regimes and lightning frequency and seasonality, and consequently in fire frequency and severity, also will occur at the landscape scale driven by changes in climate.

Because different climatic variables will not move uniformly in space, other important responses to climate change will probably only be characterized adequately at the landscape scale. Integration of remote sensing and geographic information systems (GIS), and modeling capabilities will facilitate work on effects at large spatial and temporal scales.

Modeling

Research will be supported by several types of modeling efforts. Traditionally, management-oriented models are empirically-based, including classical growth and yield models and hydrologic models. Empirical models (also called top-down models) are carefully validated with field data, and they lend themselves to management application. They are not well-suited for examining forest ecosystem processes, however, but they certainly could be useful in some cases.

In contrast, process-based models are useful for examining the behavior of forested ecosystems. The mere attempt to construct conceptual process models often uncovers critical research needs regarding the function of ecosystems or their components. Process models (also called bottom-up models) may be used to describe the biological and physical processes governing ecosystem behavior and response to changes in environment. Because of their complexity and the difficulty of validating them with field data, however, process models do not lend themselves easily to direct application in forest management.

Phenomenological models are intermediate between empirical and process models. They are based upon process knowledge without requiring extensive process detail, thereby representing process phenomena; however, phenomenological models may use many empiricisms. Phenomenological models are particularly useful in bridging the gap between process and empirical models because they can convey essential process information to empirical models that otherwise are insensitive to differences in processes.

For different applications, separate model types will be required. Some models will have direct application in management. Others will be useful in conceptualizing and synthesizing process research, and some will have applications to policy. These models should be developed during the early stages of data collection and should serve as the framework for monitoring and process research.

CURRENT U.S. FOREST SERVICE RESEARCH

The USFS has supported research on forest responses to atmospheric pollutants since the early 1970s, and research on the impacts of climate and weather on forests for many decades. The USFS has been a national leader in acidic deposition research through the Forest Response Program (in cooperation with Environmental Protection Agency and NCASI). The funding level for atmospheric deposition research in FY 1987 of $13 million includes: (1) the Forest Response program and its forest research cooperatives ($8.2 million), Southern Commercial, Spruce-Fir, Western Conifers, Eastern Hardwoods, and Vegetation Survey; (2) research on specific ecosystems including sensitive alpine wilderness lakes ($3.0 million); (3) research on effects on aquatic ecosystems ($1.7 million); and (4) operation of 11 wet deposition monitoring stations ($146,000). In addition, the USFS has been a leader in researching ozone effects on individual trees and on ecosystems, particularly focusing on changes in species composition resulting from damage due to ozone.

All eight Experiment Stations have work units actively engaged in research related to forest-atmosphere interactions. These efforts fall within USFS Research categories: Timber Management, Forest Environment, Forest Fire and Atmospheric Sciences, Forest Insect and Disease, and Forest Inventory Economics and Recreation. Specific projects are listed in Appendix C.

In addition to the FRP, the USFS has an extensive network of forest monitoring and measurement as part of its traditional programs aimed at managing and protecting forest resources to improve timber, air, and water resources on the lands within its jurisdiction. These include efforts that have been ongoing for decades, in many cases, such as: (1) FIA surveys which assess timber supply every 10 years; (2) Forest Pest Management (FPM) surveys which report on forest health and insect, disease and pollution impacts; and (3) Experimental Forests, Rangelands, Watersheds, and Research Natural Areas. Some of these experimental areas, which cover all major ecosystems and climatic conditions in the United States, have been in existence and monitored continuously for more than 50 years. This experience provides the USFS with an unequaled base upon which to build its priority research program and makes it uniquely qualified to provide the necessary leadership in examining climate-induced changes in forested ecosystems. These existing USFS programs can be built upon to address the effects of climate change and variability and the effects of altered atmospheric chemistry on forest health and productivity.

In addition to long-term research programs, the USFS conducts numerous related activities in response to the following official mandates:

- The Clean Air Act, for which prevention of significant deterioration (PSD) of air quality and associated permits are evaluated for class I (wilderness) areas;
- The Wilderness Act;
- The Endangered Species Act; and
- The National Forest Management Act, for which monitoring the effects of land and management activities is required.

The influences of climate and weather on forested ecosystems are an integral part of USFS research, with an emphasis on understanding and predicting forest growth and health in today's climate. Within the current USFS program, several areas of research contribute directly to a greater understanding of forest-atmosphere interactions: the influence of environmental and biological factors on tree and stand development; remote sensing techniques for inventory and management of forest stands; tropical forestry; and watershed processes, particularly the influence of water availability on tree growth; and the role of actively growing trees in the hydrologic cycle.

PROGRAM RESEARCH ELEMENTS

Effects of the Atmosphere on Ecosystems

1. *Energy, Carbon, Water, and Nutrient Cycling* - **Determine the simultaneous responses of energy, carbon, water, and nutrient cycles with altered physical and chemical atmospheric conditions.**

1.1 Overview of Key Scientific Issues

Ecosystems are composed of many interrelated biogeochemical cycles operating simultaneously. Generally, ecosystem processes have a tendency to resist change. The processes driven by bacteria and fungi in particular have a great ability to acclimate or adapt to changes, although the extent to which these organisms can adjust is eventually limited. A major concern is that acclimation will occur within broad limits, but once thresholds are exceeded, the ecosystem will disintegrate rapidly (Hutchinson, 1948; Waide, et al., 1974).

Global climate change will cause modifications in some of the basic cycles (water and carbon) and in temperature and solar radiation, which drive many of the cycles. New research emphasis will be on the linkages and interdependency between the ecosystem cycles and a changing global atmosphere. This approach may reveal unforeseen interactions that are important to ecosystem responses. Changing temperature, soil moisture, and atmospheric inputs of pollutants could modify biological processes which regulate elemental cycling (Swank, 1986; Harvey et al., 1987). Some cycling may be affected presently due to stresses from multiple air pollutants. Climate change may lead to additional interactions. Another point of emphasis should be on those nutrient cycles that are strongly dependent on biologically-linked processes. Carbon (C), nitrogen (N), sulfur (S), and, to a lesser extent, phosphorus (P) cycling are mediated by bacteria (e.g., N2-fixation, N and S oxidation and reduction) and fungi (e.g., C decomposition, mycorrhizal associations, P uptake).

1.2 Carbon Cycle

Photosynthesis changes light energy into chemical energy. This process is sensitive to changes in environmental factors, such as light and Carbon Dioxide concentrations, and its rate can be expected to change with changes in global climate. It may also be influenced by pollutants such as ozone. Research is needed to determine how the rate of photosynthesis will change at the stand and ecosystem level with increased temperature, increased Carbon Dioxide levels, increased or altered atmospheric deposition and levels of air pollutants, altered light composition, and changes in other environmental variables. Because the photosynthetic process is the primary integrator of carbon, water, nutrient, and energy cycles, research is needed not only on the direct effects of these individual variables and the subsequent effects on photosynthetic rate, leaf surface area, stomatal conductance, photosynthetic capacity, chlorophyll content, leaf age, and numerous other factors important in photosynthetic efficiency at several stages from budbreak to development of cold hardiness.

Carbon fixed in photosynthesis is transported throughout the plant for use in respiration, growth, and storage. Specific allocation processes determine the priority in which plant parts receive carbon fixed in photosynthesis. As with photosynthesis, these allocation processes are responsive to environmental variables. Research is needed to determine: (1) if atmospheric deposition, air pollutants and temperature will modify the allocation of carbon in plants so that the shoot-root balance is changed; (2) if reduced root growth will alter water and nutrient availability and modify root mycorrhizal and root-root pathogen relationships; (3) if increased global temperature will significantly increase the respiration rates of plants; and (4) if reduced photosynthesis will reduce seed production. If the plant vigor is modified because of changes in photosynthesis or carbon allocation, plant pathogen and insect relationships along with numerous other ecosystem relationships also will change. An increase in respiration leading to a loss of vigor in old growth stands could have devastating effects in some forest regions, particu-

larly in the West and in parts of the East. Integrated research must be conducted to determine the importance of these changes and evaluate priorities for management practices.

An important part of the carbon cycle is the decomposition of dead tissue by microorganisms and the release of Carbon Dioxide back into the atmosphere. Other nutrient cycles are often rate limited by this process. Research must be conducted to determine if global climate changes will affect rates of decomposition. If the rate is slowed, litter may accumulate and retain nutrients needed for growth. If decomposition rates increase, ecosystem nutrient retention may be affected.

Example Research Areas:

(1) Initiate research on the effects of simultaneous altered Carbon Dioxide levels, increased temperature, and altered light quality on photosynthesis and carbon allocation in major forest tree species (see also research element #8).

(2) Accelerate research on the effects of atmospheric deposition on carbon allocation in tree species with emphasis on site of allocation and subsequent effects on mycorrhizae and root pathogens.

(3) Initiate research on effects of global climate change on old growth stand vigor.

(4) Initiate research on rates of decomposition in relation to global climate change.

(5) Develop methods for scaling up from whole-tree physiology studies in controlled environments to trees growing in the forest environment.

1.3 Water Cycle

Global climate change is expected to cause changes in water availability in many ecosystems. Water movement and availability to forest vegetation are critical factors in ecosystem behavior because of the effects on the physiology of plants and nutrient cycling. Water stress in the temperate forest is expected to be one of the most devastating effects of changes in the global atmosphere. This stress could lead to large scale changes in the composition and distribution of forests. Small changes in precipitation patterns may affect carbon balance and allocation, nutrient requirements, and nutrient retention in the soil plant system. Research on the components of the hydrologic cycle, especially on evapotranspiration by overstory and understory vegetation, is needed to allow modeling of each component of the cycle independently. Knowledge of water movement and evapotranspiration for overstory and understory plants is important for determining how energy is utilized by the forest community and how nutrient cycling may be related to the water cycle (Kaufmann et al., 1987).

Studies should focus on developing procedures for estimating evapotranspiration based upon physiological and meteorological factors on a regional scale. This will ensure that the effects of environmental changes on evaporative loss from forest communities can be assessed through their effects on such factors as leaf area, root and stem-conducting tissues, stomatal behavior, and evaporative demand. The increased knowledge of water cycling in forest stands will be particularly useful in assessing the interactions of the water, carbon, and nutrient cycles and the energy balance of forest communities. Furthermore, this knowledge will aid in determining the integrated effects of environmental change on forest ecosystem behavior.

Riparian areas, especially in the western United States, are particularly vulnerable to changes and shifts in the water cycle. Large scale changes could occur with increased global temperatures and decreased precipitation. These areas should also be the focus of long-term research.

Example Research Areas:

(1) Accelerate research on the possible impacts of climatic change on the cycling of water through forested and rangeland ecosystems.

(2) Evaluate the interaction of changing climatic conditions on water stress for key species in major ecosystems.

(3) Increase research on expansion, contraction, and migration of riparian zones and other ecotones in response to changing water regimes.

(4) Examine influence of changing climate on the distribution of riparian areas and rangelands, fire frequency, and the distribution of major tree species.

1.4 Nutrient Cycling

Stable, undisturbed ecosystems have nutrient cycles that are generally conservative where losses from leaching, sediment movement, or biogenic gases are balanced by inputs from the atmosphere and rock weathering (Mooney et al., 1987). Changes in atmospheric deposition and global climate may alter ecosystem nutrient cycling and retention by increasing supply or by affecting processes. More information is needed to be able to model specific outcomes. For example, the biological systems that transform nutrients in the soil require water, which is a function of climate. The uptake of nutrients is associated with water uptake. Temperature plays another essential role; within certain limits, the higher the temperature, the faster are nutrient cycling processes. Major differences occur in litter decomposition in tropical forests and temperate forests based on differences in moisture and temperature. In addition, atmospheric deposition may alter the pool size of some cycled nutrients. The net result could be changes in relative growth rates between species and disadvantageous changes in forest composition, soil fertility, and water quality.

Within limits, atmospheric deposition can act as a fertilizer. Atmospheric deposition to ecosystems is known to be changing. Ecosystems in some areas with high deposition rates could be near thresholds. Recent research has suggested that dry deposition is a major source of nutrients and pollutants to some forested ecosystems and watercourses (Lindberg and Lovett, 1985; Norton et al., 1988; Young et al., 1988). Dry deposition could have significant impacts on canopy exchange processes, tree nutrient relations, forest productivity, and water quality. The specific fates and impacts of dry deposition in forests are poorly known. New research is needed to identify pathways of material movement after deposition to forest canopies and to quantify impacts on the nutrient economy of forest stands. Research will entail baseline studies of nutrient cycles in combination with dry deposition measurements.

Cycles of S, N, and nutrient cations, and the mobility of elements such as aluminum can be influenced by atmospheric deposition (Hutterman, 1985; Matzner and Ulrich, 1985; Shortle and Smith, 1988). Specific effects vary by soil types. Effects may be event-related or occur over longer time periods (Johnson, 1986). For example, much of the forested area in the Southeast is located on old, weathered soils (Ultisols) having few primary minerals and low base saturation, making it susceptible to long-term effects of deposition. The critical role of sulfate adsorption in consuming protons and how sulfate desorption progresses under changing sulfate input require further study. In much of the Northeast and West, soils are younger, less well-developed and contain abundant primary minerals. Replacement of exchangeable bases by hydrolysis of primary minerals is important to the acid neutralizing capacity of these soils. The rates of hydrolysis are related to water residence time and flow pathways and may be affected by new climatic regimes.

Example Research Areas:

(1) Initiate studies of decomposition and nutrient cycling under altered temperature and moisture regimes expected from global climatic change.

(2) Accelerate research on the role of dry deposition of nutrients and trace elements in forested ecosystems, particularly in areas where dry deposition is the dominant form of atmospheric deposition.

(3) Continue or initiate work on forest soil types in areas where the potential exists for effects to develop due to atmospheric loading.

1.5 Effects of Ozone

Research over the past two decades has demonstrated that moderate to high levels of ozone cause the selective death of forest tree species and significant changes in forested ecosystems (Miller and Elderman, 1977). These

high to moderate levels of ozone are widely distributed across the eastern United States. The FRP has focused on the effects of acid deposition with ozone considered as a nitrogen-derived pollutant of secondary concern. Recent evidence suggests ozone may be a significant factor in causing mortality to trees in several areas. The FAI will address ozone effects directly.

Insufficient information exists on the effects of chronic low levels of ozone on forest trees and there is also little information on short-term exposures to high concentrations. The general mode of action of ozone has been defined and a range of susceptibility to ozone damage within and between some species has been determined. However, further research is needed to determine the ozone resistance mechanisms in trees and to develop (via biotechnology) more resistant trees for use in ozone impacted forests. Research also is needed to determine and understand how low chronic levels of ozone alone and in combination with other air pollutants and climatic change affect the more susceptible forest tree species. As climate changes occur, additional research will be needed to understand the impacts of climatic changes on ambient ozone levels, and the effects and role of ozone exposure in combination with other climatic stresses.

Example Research Areas:

(1) Initiate research to determine the critical levels of ozone alone and in combination with other pollutants leading to physiological and anatomical changes following chronic sub-symptomatic exposures to sensitive forest types and also in response to short-term exposures to high levels of pollutants.

(2) Initiate studies on the air pollution sensitive, nondominant plant species in impacted ecosystems, such as herbs and shrubs.

(3) Initiate research on mechanics of ozone injury in order to investigate the genetic control of resistance in loblolly, Jeffrey, and ponderosa pines for future selection programs and bioengineering of resistance into planting stocks.

(4) **Continue studies of the effects of ozone on community dynamics in sensitive forest types.**

(5) Evaluate the influence of climatic changes on ozone concentrations.

2. *Species Life Histories and Distributions and Community Compositions* - **Develop methods to predict changes in species life histories and distributions, and community composition and distribution resulting from global climate change.**

Overview of Key Scientific Issues

Important population processes such as seed production (including pollen production, pollination, seed maturation, and seed dispersal), natural seedling establishment, and tree death are influenced directly or indirectly by atmospheric conditions. Examples of direct influences include the effects of air pollution, temperature, moisture, and strong winds. Examples of indirect influences include the impacts of air pollution on climate changes and the subsequent effects on species competition factors (Shugart et al., 1986; Warrick et al., 1986). Alteration of one or more of the key population processes would lead to changes in community composition and, eventually, to changes in the distribution of individual species. This issue should be approached in conjunction with the major long-term studies and modeling efforts.

Two research approaches appear promising for this essential research. First, old-growth forests provide an opportunity to evaluate the potential effects of a changing physical and chemical climate on tree mortality and the relationship of the pattern of mortality to landscape features. Old-growth forests are suitable for this research effort due to the tight energy budget that old-growth individuals have. Shifts in climate that induce stress may weaken these individuals, making them susceptible to disease and eventual premature death.

A second approach will be the establishment of studies in open top fumigation chambers along gradients of atmospheric conditions. This technique will allow testing of the genetic adaptability of the tree species in question without the need for precise temperature control. Light quality, Carbon Dioxide, and water can be controlled in

the open top chambers using techniques developed in the NAPAP-FRP.

Example Research Areas:

(1) Establish the relationships between physical and chemical climate parameters and population processes for dominant tree species.

(2) Evaluate how population processes and species abundance and distributions in major forested ecosystems would respond to potential changes in the physical and chemical climate.

(3) Examine the role of genetic diversity in the response of forest tree species to changes in the physical and chemical climate.

(4) Establish old-growth forest plots to follow life history changes. Because these plots are among the most likely to show change, other studies should be conducted jointly on these plots.

(5) Determine how old-growth plant responses would influence future species composition and species distributions.

(6) Use remote sensing products to determine landscape scale shifts over time in community ecotones and vegetation composition. This would be accomplished by development of a Geographic Information System (GIS) that includes chronologies of the distribution of vegetation type obtained from remote sensing (restricted to natural areas), disturbance histories, topographic themes, and spatially and temporally referenced data on community composition. Intensive efforts will be focused on long-term monitoring sites (see #13); however, with continued development, this approach should be applied to larger areas which contain extensive natural areas.

3. *Water Yields, Erosion, and Sedimentation* - **Develop methods to predict changes in water yields, erosion, and sedimentation in forest and rangelands resulting from climate change.**

Changes in the physical and chemical climate can be hypothesized to either increase or decrease water yield depending on the areas of concern. Vast areas exist in the western United States where the transition from forest to non-forest vegetation is dependent on small changes in temperature and/or precipitation. Impacts of elevated levels of Carbon Dioxide and other pollutants also may influence shifts in vegetation types. In many areas in the eastern United States, if species composition changes from soft woods to hardwoods due to climate change, water yields may be affected (Swank and Douglass, 1974). Changes in biomass and leaf and rooting characteristics that accompany changes in vegetation type will result in changes in interception and transpiration. This may either increase or decrease water yields depending on the direction of the vegetation change. In addition, temperature plays a role in the amount of precipitation that occurs as snow and in the timing of snowmelt runoff.

Alterations in water yield are of special interest where water supplies are critical and where snowmelt floods are common. The total amount and timing of water flow also is closely linked to the routing of nutrients and sediments from forested watersheds and to the maintenance of valuable fisheries resources.

Erosion from forests is minimized by high infiltration rates, protection of mineral soil by organic horizons, and stability provided by dense root systems. Changes in vegetation from forest to non-forest species and declining health of forest stands, brought on by drought or atmospheric deposition, will reduce protective soil cover and root density. Subsequent increases in erosion and sedimentation will have serious consequences in both on-site productivity and downstream values. In regions heavily dependent upon irrigation, such changes in sediment yield will lead to loss of storage capacity in reservoirs and damage to water distribution systems. The problem may be most severe at higher elevations where ecosystems are more fragile and atmospheric deposition may be greater, and on steeply sloping lands already subjected to extreme climatic events.

Example Research Areas:

(2) Application and further development of hydrologic models to simulate long-term

impacts of changing climate on the timing and quantity of stream flow.

(4) Conduct plot studies to evaluate evapotranspiration losses from major vegetation types in potentially affected regions of the U.S. and evaluate influence of changes in forest type on water yield.

(6) Accelerate research on the role of rooting density on surface erosion, slow moving earth flows, and debris slides.

(8) Expand efforts to correlate annual sediment yields to annual water yields under various vegetation scenarios.

Forest fire intensity and damage depend on the vegetation amount and structure (the forest type), on the moisture content of the fuels (Fosberg and Furman, 1973; Fosberg et al., 1981), and on weather conditions. The relationship between the forest stand and fire is that fine fuels control fire spread (Rothermel, 1972), while large fuels dominate fire intensity (Deeming et. al., 1972). Climate, particularly precipitation, exerts a strong influence on forest type and the fuels produced.

Short-term variations of weather as expressed in humidity, seasonal rainfall, and wind determine the frequency and intensity of forest fires. Because humidity, seasonal rainfall, and wind are poorly predicted in climate change scenarios, a series of possible future states must be examined. A higher mean temperature is expected, which will increase fire danger. An increase in humidity and a decrease in wind result in lower fire danger, and conversely, a decrease in humidity and an increase in wind result in higher fire danger. Because the threshold for severe fires will remain constant, a change in mean values will result in a changed distribution of fire frequency and severity.

A change in fuel loading (forest type) will occur over a period of time as ecosystems respond to climate change. In much of central North America, which experiences a spring and fall fire problem, a major shift in forest fire suppression activities may occur because of decreased summer precipitation. Using the scenario of Warrick et al. (1986) and Shugart et al. (1986), shrubs and herbs are expected to replace the dominant hardwood forests.

The original forests are likely to be fire tolerant by structure rather than genetics. Most arid zone shrub species survive fire through genetics; they produce seed which can survive fire and may depend on fire for germination, or they can produce new growth from roots well protected by soil (Noble and Slatyer, 1977). The transition period, with a remnant species from the old climate structurally safe from fire and an invading species, genetically aggressive with fire occurrence, would likely lead to a more rapid forest change. Specifically, the lower canopy shrubs which are genetically fire tolerant would provide a continuous fuel ladder to the earlier forest canopy. Drought or increased frequency of drought would increase the frequency and severity of fires in deciduous forests and make them more susceptible to replacement by fire tolerant shrublands.

Example Research Areas:

(1) Determine the changes that might be expected in the amount and structure of forest fuels resulting from change in the physical and chemical climate.

(2) Determine the effect of changed drought frequency and severity on fuel moisture and therefore on fire severity and frequency.

Aquatic ecosystems will respond to shifts in patterns of climatic variables as the effects are integrated over the landscape and through stream channels. Climate change will affect the physical and chemical characteristics of lakes and streams as influenced by the hydrologic and geologic settings and current and future pollutant regimes. Changes in habitat characteristics due to likely changes in climate cannot be predicted at present.

Example Research Areas:

(1) Develop classification schemes for valley floor and aquatic environments.

(2) Develop methods to predict significant changes in important aquatic habitat characteristics for likely changes in climate.

Potential effects on wildlife should be examined within a landscape context. Shifts in patterns of weather and climate across the landscape will be variable, e.g., summer temperatures may vary in a different direction on the landscape from winter precipitation. The mosaics of forest and range patches could move spatially influencing the distribution of animals. The needs and scale of landscape sensed vary greatly among species. In addition, landscapes have a wide range of patterns caused by natural processes and mankind. Changes in climate may shift the distribution of biological components. Thus, important areas, such as designated wilderness, could be significantly altered.

Example Research Areas:

(1) Initiate research on the effect of climatic changes on winter range distributions and productivity.

(2) Initiate research on the effect of climate versus the effect of grazing of domestic livestock on the productivity of affected ecosystems.

(3) Initiate research on developing, through biotechnology, grasses, shrubs, and forb species capable of adapting and surviving climate changes.

(4) Develop methods for predicting changes in physical habitat pattern according to probable changes in climate.

(8) Given a range of likely changes in climate, predict changes in habitat pattern using knowledge developed in (4) and (5), and predict effects on wildlife population and ranges using knowledge developed in (6) and (7).

Example Research Areas:

(1) Initiate research on rate changes in nutrient cycles which may occur as a result of soil temperature changes associated with global climate change.

(2) Initiate research on the function of mycorrhizal and nitrogen-fixing symbiotic microbes associated with changes in soil temperature and changes in host range.

(3) Continue research to quantify disease and insect caused morbidity and mortality following air pollution effects in combination with other stresses on sensitive forest types.

(4) Evaluate the present range of radiation flux density in order to evaluate the need for research on changes in ultra-violet light levels on major forest tree species, pathogens, insects, and epiphytic lichens.

(6) In western forests already damaged by air pollution, accelerate research on changed incidence of fungal diseases and insect infestations in combination with other occurring stresses.

(7) Initiate research on obligate pollination mechanisms involving highly adapted insects and plants that would be disrupted by climatic change and possibly earn endangered species status.

(8) Initiate research on obligate relationships where insects are the food source which may be disrupted by climatic shifts.

(9) Integrate research (see element #1) to determine impacts of insects and disease organisms on whole-tree carbon fixation and allocation.

Because the nature and form of the functional relationships between whole tree physiological processes and climatic variables are poorly understood at present, the magnitude and rate of future changes for most tree species and forest regions of the United States cannot be accurately predicted from existing information or models. The biological effects of climate induced changes in carbon budgets and allocation on wood anatomy and on physical and chemical properties of wood also are poorly understood. Thus, considerable research is needed to facilitate predictions of impacts of future climate changes on the quantity and quality of wood produced in major forest regions of this country. This research should be focused at the level of whole tree physiology, which will provide new process information essential to modeling studies described later.

These research areas are strongly linked with those in research element #1.

Changes in insect or disease populations will also affect work quality through reduction of strength properties. (Becker, 1987)

Example Research Areas:

The influence of the canopy on atmospheric water balance is significant and dramatic. The influence of the canopy on exchanges of other atmospheric gases and aerosols may be equally significant. From a physical perspective, the forest canopy introduces a significant amount of exchange surface into the atmospheric surface layer. Thus, radiation is absorbed, emitted, and reflected within this layer. The distribution of radiation gives rise to a distribution of temperature and, in turn, of wind and turbulence.

Example Research Areas:

(1) Quantify the exchange of radiation and momentum through a forest canopy to develop an understanding of the processes of exchange of mass as driven by energy and momentum exchange in various forest canopies. This should be accomplished in association with existing ecological and process research activities although not all locations should be considered.

(2) Develop a "community" atmosphere model for both conifer and deciduous trees in flat terrain and with continuous homogeneous forest canopies.

(3) Adapt the community forest canopy model to irregular forests, clearings, edges, etc. to allow investigation of effects of irregularities on canopy processes.

Effects of Ecosystem Change on the Atmosphere

10. *Emissions of Forests and Forest Fires* **- Refine estimates and mechanisms of emissions from prescribed fire and wildfire in forests and related ecosystems.**

Overview of Key Scientific Issues

Trace gas and particulate emissions associated with worldwide biomass combustion during wildfires, forest clearing, and forest management operations may be of sufficient magnitude to affect global climate change. Atmospheric concentrations of carbon dioxide and the trace gases methane, nitrous oxide, and carbon monoxide have been increasing at unprecedented rates during recent decades (Ramanathan et al., 1985).

Neither the frequency and extent of biomass combustion in natural ecosystems nor the effects of fire severity and vegetation structure on trace gas emissions are adequately quantified. Moreover, fire occurrence could be dramatically altered by global climate change (see element #4). Fire impacts may be expected to vary with the altitude of smoke injection into the atmosphere, rates of dispersion, and rates of trace gas or particle reactions that transform emission products. Post-fire emissions of reduced compounds from soil and sediment, as a result of biogenic or microbial production, may significantly compound those associated with direct combustion (Anderson et al., 1988).

The scale and impact of biomass combustion varies dramatically among major biomes, but the relative importance of land clearing in the tropics, forest operations in the temperate forests, and wildfires in Mediterranean-type ecosystems or boreal forests has not been established.

Example Research Areas:

(1) Determine the global extent of burning from fires.

(2) Determine trace gas and particulate emissions and fire physical properties.

(3) Model smoke emissions and photochemistry of emitted trace gases.

(4) Make estimates of the influence of climate change on fire frequency and emission rates.

11. *Transport and Dispersion of Forest Pollutants* **- Improve understanding of transport and dispersion of pollutants associated with prescribed fire and wildfire.**

Overview of Key Scientific Issues

Wildfires and prescribed fires in forests and rangelands are important regional and global sources of atmospheric aerosols (Sandberg, 1987). Smoke particles and hydrocarbon emissions from fires contribute to haze episodes that may affect environmental quality and human health to the extent that fire may be restricted as a management tool (Fahnestock and Agee, 1983). In regions where climate change has increased the frequency of drought, the resulting increase in wildfire will contribute additional atmospheric pollutants to the atmosphere. However, frequent droughts will limit fuel accretion.

The ability to understand the effects of increased wildfire and its impacts on human health, air quality, and prescribed fire use, will depend upon improvements and validation of atmospheric transport and dispersion models such as the Topographic Air Pollution Analysis System developed by the USFS Rocky Mountain Forest and Range Experiment Station (Fox et al., 1987).

Simple, one dimensional models of transport and diffusion of smoke have major shortcomings in that wind direction and speed are assumed to be spatially constant. Case studies, using individual weather events and climatology have shown that plume deformation is frequently underestimated by the simple one dimensional models (Fosberg, 1985; 1987). The methods used to determine the wind fields for properly estimating the dispersion are fairly well established. The most common method is through use of dynamically constrained objective analysis (Davis et al., 1984; Fosberg, 1984). The shortcoming of this procedure is that these models are currently able to only describe case events, even when climatological data are used. That is, the models cannot accept probability distributions of wind (Lamb and Hati, 1987).

Example Research Areas:

(1) Develop dynamically consistent wind and stability climatologies which can be used in transport and diffusion estimates.

(2) Develop the concepts and models of transformation of individual plumes to regional aerosols.

(3) Determine the removal processes of smoke particulates and gasses from the atmosphere.

12. *Changes in Forest Area* **- Determine effects of large changes in forest area (including fire) on energy, carbon, oxygen, water budgets and on composition of the atmosphere.**

The USFS measures the impact of a variety of land use changes on water budgets as they affect stream flow, erosion, and sedimentation. Such conversions in land use include clearing forests for grazing and row-crop land; agricultural land to forest land of either hardwood or conifer species; and various wildland conversions associated with fire where grassland, shrubland, and forest conditions change over periods of 1 to 100 years. A large amount of data are available to document the magnitude of these changes and in some regions, this information has been used to evaluate the impact of land use changes on regional hydrology. This type of evaluation should be carried out in other areas where fire and social trends have changed the landscape.

These traditional studies, however, have failed to document the impact of land use change on the emission of gases, site humidity, and fixation of carbon. Changes in regional land use may affect local climate in subtle ways, but continental climate controls the response of vegetation and the basic aridity or wetness of landscapes.

Research on the effects of changes in climate on land use should focus on: (1) the impact on water, nutrient, and energy budgets in comparison to land use changes, and (2) the response of forest landscapes relative to emission of gases and carbon fixation. Such research will improve our understanding of changes in hydrology caused by man versus climate and the feedback processes from the landscape to the atmosphere that will either moderate or increase climate change.

Three significant conversions in land use (or changes in soil condition) are occurring. These include: (1) conversion of forests to agricultural land, (2) conversion of forests to scrub or desert land by over grazing and fuelwood mining, and (3) swamping of both mineral and forest soils by increased precipitation. Changes in forest area could also be in response to climatic change.

12.1 Agricultural Conversion

The conversion of tropical forests to savannah or agriculture leads to a 20 to 30 percent increase in albedo, and thus may lead to a change in global temperature (Sagan et al., 1979; Henderson-Sellers and Gornitz, 1984; Dickinson 1983). Whether changes in albedo influence water budgets or only the distribution of energy is unknown. Predictions of climate change cannot be made on the basis of a single energy factor.

Conversion of forests to grass or agricultural land typically diverts water from evapotranspiration to stream flow. Whether or not these effects are important to regional climate must be evaluated on the basis of the amount of land that is changed as a percentage of the entire basin and the estimate that the difference in forest and grass evapotranspiration is as much as 25 percent of the rainfall.

A significantly large pulse of carbon may possibly be released to the atmosphere when forests are cut and burned and the permanent change to agricultural land may continue to result in less carbon fixation. However, Lugo et al. (1986) show that carbon fixation on agricultural land and tropical forest is similar.

The critical needs in this area are to use existing information to predict changes in basin hydrology, to evaluate the relative importance of large land mass evaporation and ocean moisture transported over the land mass, and to greatly extend our knowledge of carbon fixation and both methane and carbon dioxide evolution from representative landscapes.

12.2 Overgrazing and Fuelwood Mining

Overgrazing and fuelwood mining in arid regions leads to more dust, reduced incoming radiation, reduced air stability, and fewer convective storms (Bryson, 1972); however, Lamb (1982) and Kutzbach and Guetter (1984) attribute associated desertification to changes in global circulation rather than local albedo changes. Similarly, overgrazing and fuelwood mining in humid climates have occurred during changes (increased precipitation and cooler temperatures) in global climate (Barber, 1981; Birks, 1986; Bradley et al., 1987). Although cause and effect are not defined explicitly, subtle differences in climatic variables of temperate forests are related to tree species occurrence (Denton and Barnes, 1987a; 1987b).

Man-caused changes in land use may intensify local climate change to increased aridity or wetness, but climate change itself is the driving factor (Birks, 1986; Harrington, 1987).

Afforestation or reforestation changes the local water budgets but the establishment of trees may be difficult to accomplish in dry areas unless changes in climate bring more water to the area (or ground water irrigation is supplied). In humid areas, past changes in climate may alter soil conditions and hinder reforestation.

12.3 Land Swamping (Raised Water Tables)

Swamping or raising of water tables to the surface of mineral soils creates an anaerobic environment that leads to significant emissions of methane and carbon dioxide. The wetness and extent of these anaerobic landscapes globally produces enough methane and carbon dioxide to account for at least one-third of the greenhouse warming phenomenon at present (Crill et al., 1988; Bolin et al., 1983). In the northern hemisphere, where temperatures are cool and water seeps over the surface, large expanses of peatlands have developed (Kivinen and Pakarinen, 1981). In the mid latitudes and southern hemisphere, large organic soil areas are less important but the swamping of mineral soils on a seasonal or annual basis is significant (Lugo, pers. comm.).

Research is needed to measure gas evolution from a variety of landscapes in various microenvironments and balance these values against carbon fixation. Because these processes are driven by sunlight, temperature, and precipitation, environmental scaling information (area, temperature, day length, growing season, etc.) is needed to reduce the error of extrapolating these processes to a regional and global level.

Example Research Areas:

(1) Quantify gas evolution and carbon cycling by forest land use type; define temperature, moisture, and organic matter type controls on gas evolution; and define annual rates of carbon fixation by land use type.

(2) Initiate research on the effects of large-scale forest removal on carbon, water, and oxygen budgets and relative abundance in the atmosphere.

(3) Determine emissions of trace gases from forest removal.

(4) Support remote sensing of land use on a regional and global basis; emphasize ground-truthing in the United States and other areas.

Assessment of Long-Term Changes

13. *Long-Term Ecosystem Monitoring* **- The USFS has defined monitoring as the long-term, periodic measurement of selected physical and biological parameters for establishing base lines and to detect and quantify change over time. This plan will institute and use long-term ecosystem monitoring, particularly building on existing Experimental Forests, Experimental Rangelands, and Research Natural Areas to accomplish the following:**

(a) **determine long-term trends in forest condition, rangelands and related ecosystems;**

(b) **determine the extent and magnitude of current forest condition in relation to natural and anthropogenic stresses;**

(c) **identify critical variables necessary to assess ecosystems response to changes in physical and chemical climates, and devel-**

op methods to monitor these variables on a wide basis, including monitoring within Forest Plans;

(d) **identify ecological, physiological, and/or morphological characteristics that can serve as indicators of chemical and/or physical environmental changes; and**

(e) **verify model-based predictions of changing forest condition in relation to a changing environment.**

13.1 Long-Term Measurements and Resource Inventories

Recent studies examining the impacts of air pollution on forest productivity have been hampered by the lack of relevant, long-term data bases. Future assessments of climate change will face similar limitations unless adequate monitoring is initiated. Some monitoring has begun as a part of FRP; these activities have generated useful information. However, information about the condition of total resources on land management units is not available in appropriate magnitude, detail, and accuracy to serve as baseline information for detecting future impacts of climatic variance on natural resources. In addition, some large data bases have been accumulated as a result of the Resources Planning Act assessments, Forest Plans developed under the National Forest Management Act, and periodic state-level forest inventories. However, these inventories have been limited geographically; future information should be collected systematically across forest regions and incorporated into regional-scale models.

Planning for a continuous monitoring program must begin with intensive research to select appropriate measures and to develop the necessary statistical framework. The goal of this research is to provide the information necessary to develop and implement a monitoring system useful in evaluating global climate change. The monitoring system will collect data that enable the detection, interpretation, and prediction of specific changes in parameters valuable to the USFS in the context of its basic missions. Careful thought must go into this plan in order to ensure that: (1) representative ecological units are selected for measurement; (2) accumulated data can be compared globally; (3) appropriate parameters are measured simultaneously; and (4) sampling continues well beyond the life span of the dominant organism. Such planning is currently underway through the National Vegetation Survey and the Synthesis and Integration team of the FRP. Monitoring data should cover the range of ecosystem compartments and the transfers between such compartments (atmosphere, geosphere, hydrosphere, and biosphere). Sample sites in sensitive ecosystems with climatic histories that are asynchronous with current atmospheric climate should be included to help provide an early warning of ecosystem changes, and the emphasis should be on the magnitude and direction of change over time rather than on current conditions. A critical set of variables must be selected for measurement so that the program and its value can be maintained indefinitely. Archival and analysis responsibilities must be identified to ensure that the data are preserved and useful to current and future managers and scientists.

The Forest Service has recently published a set of guidelines for measuring the condition of wilderness ecosystems (Fox et. al., 1987). These guidelines were developed by a large group of scientists for the purpose of supporting air resource management programs in the Forest Service and could serve as the basis for developing monitoring programs in wilderness areas.

All FAI-PRP monitoring efforts should complement any existing activities in the USFS including those of the FIA, FPM, and Forest Planning in the USFS. Several monitoring programs also are developing in Europe. International cooperation should be continued within the FAI-PRP because the changes in climate are global. New monitoring efforts should build upon existing networks and the historical data available. Linkages should be established with long-term ecological research and monitoring activities sponsored by the National Science Foundation (NSF) (Callahan, 1984), other federal agencies (DOI, DOE, NASA, TVA, EPA), and states and universities (Halfpenny and Ingraham, 1984). These linkages are critical to ensuring compatibility of the PRP with these programs. Additionally, valuable insight into the design and operation of a long-term monitoring program can be gained from interaction with existing programs outside of the USFS. As much as possible, long-term measurements should be integrated with existing and planned monitoring efforts within the Forest Response Pro-

gram, Forest Service Experimental Forests, Experimental Rangelands, and Research Natural Areas.

Modeling is a critical, integral part of long-term environmental monitoring. The monitoring system will develop information on measurements at individual sites. These data will be used for spatial and temporal extrapolations and identification of possible spatial and temporal correlations of forest health, pollutant exposure and stress due to climate change. These data will also support evaluation of cause and effect and dose-response relationships through the use of qualitative and quantitative modeling approaches. Modeling activities will develop a sound conceptual and statistical framework for the monitoring program. In order to monitor efficiently across the spectrum of spatial scales, modeling must be viewed as an integral part of this activity.

Remote sensing and GIS techniques can be used to minimize the costs of monitoring the responses of regional and global ecosystems to climate variables, and to provide data for large scale ecosystem studies. The development of instruments and measurement techniques (supported by such agencies as NASA) should be coupled with ecosystem studies to improve the interpretation of remotely sensed data. In any hierarchial system of sampling, it is readily apparent that remotely sensed information can provide considerable economy and flexibility for some of the key measurements. Other measurements, such as biogeochemical fluxes, cannot be made from remote sensing.

The USFS has played a major role in the development of long-term research and monitoring in the United States (Likens et al., 1977; Swank and Crossley, 1988; Edmonds, 1982). These efforts should be strengthened and expanded to encompass the range of ecosystems under investigation within the FAI-PRP.

(1) Evaluation of Other Programs and Available Sites.

Some existing sites have excellent long-term records. Coweeta, Hubbard Brook and H.J. Andrews provide excellent examples of the tremendous value of high quality, long-term records in evaluating trends in atmospheric deposition and runoff chemistry. Such sites should be included whenever possible in the FAI program.

(2) Critical review and analysis of existing data bases.

Basic keywords related to long-term monitoring are "trend" and "baseline." Baselines are established conditions for monitored parameters during a given time frame; trends are tendencies for changes in monitored parameters from baseline conditions. A baseline can be established relative to past conditions and trends, therefore, existing data should be evaluated. These data should include information from Experimental Forests, University Forests, Long-Term Research areas (LTRs), Research Natural Areas (RNRs), FIA data, dendrochronological data, and other paleoecological data. These evaluations will also aid in the identification of important variables to measure, necessary model development, and in contributing to an understanding of the history of forest types and ecological zones. A national data base may be necessary to provide access to these data. Following the identification of relevant data bases, a summary and synthesis of these data will be conducted according to the needs and protocols of the FAI-PRP long-term monitoring program. This review and analysis will provide a strong foundation for the continued development and operation of this program.

Within a given ecosystem, physiological or morphological characteristics need to be identified for use as indicators of ecosystem health. Such characteristics as root/shoot ratios, leaf area indices, numbers of soil fungi present, etc. are examples that might be used for this purpose. Research is needed in each major ecosystem to determine which of these ecological, physiological, or morphological characteristics can be used for determining ecosystem status. Projects within research elements #1, 2, 7, and 8 will contribute significantly to this long-term monitoring research need.

(5) Plant response to stress.

(6) Long-term trends in deposition and ecosystem chemistry (soil, plant, stream).

Ecosystem Modeling

Ecosystem modeling is essential to the development of strategies to manage natural ecosystems in a changing environment. In order to synthesize and integrate the knowledge of processes in individual plants and whole ecosystems into strate-

gies for managing forest and related ecosystems, models must be developed and utilized to understand many of these processes and predict potential changes in the future. There are five elements to modeling that need to be addressed.

An ecosystem model is not likely to be developed by an additive combination of the individual plant models. A large number of interactions between plants are difficult to account for in individual plant process models, and the interactions with non-plant biological activity and with the physical environment cannot be fully incorporated. Generally, the models best suited for the ecosystem as a whole are empirically based where the response of the ecosystem is related to the external force. These "top-down" models can be constrained by the individual plant process models to give a top-down, bottom-up model which while empirical, also is constrained by our knowledge of processes.

(3) Modeling at the landscape scale.

This component refers to the general circulation models (GCMs) of the atmosphere. These models are very coarse both spatially and temporally, representing thousands of square kilometers with single temperature and precipitation amounts. Temporally, at best they can represent seasonal change. A typical whole plant or ecosystem model is based on time and space scales considerably smaller than those represented by GCMs. In order to successfully model the future ecosystem this difference in scale and resolution must be resolved. Also, the ecosystem model must be coupled to the global climatic change atmospheric model in order to provide the exchange of materials.

(5) Modeling as a tool for focusing on alternative scenarios.

Modeling should be recognized as a tool for examining systems that do not have unique solutions, i.e., numerous solutions are possible, because of genetic differences in plants, variable effects of pathogens and pests, catastrophic events such as fire, and uncertainties in how the ecosystem will respond to stress. The most useful output from the models of the physical and biological world are probability statements on the possible outcomes.

These stochastic outputs more accurately reflect the real world and also provide the kinds of inputs needed for decision, economic and risk analysis models that will be used to select management strategies.

(6) Decision, economic, and risk assessment models.

Example Research Areas:

(3) Develop improved growth and yield models (i.e., improve biophysical-physiological basis of such models) for managed forests under

(4) Develop post-harvest successional models for managed forests under

(5) Adapt and improve models for projecting changes in forest composition and

(6) Develop integrated process-oriented ecosystem models of forest hydrology,

(7) Develop models of impacts of physical and chemical climate change on

(8) Develop models for projecting changes in the distribution of species and

(9) Develop or adapt appropriate methods for validating ecosystem models and

for analyzing parameter sensitivity and model error/ uncertainty for

Example Research Areas:

(1) Based upon appropriate disciplinary information (e.g., hierarchical systems theory, scaling theory, landscape ecology), develop the conceptual basis for translating model results across scales and for interfacing models formulated at different scales.

(2) Develop methods for coupling ecosystem simulation models with new techniques in geographical information systems (GIS) and remote sensing.

(3) Develop methods for interfacing general circulation models (GCMs) with models of forest and related ecosystems.

16. *Interfaces between Ecological and Management Models* - **Develop methods of interfacing ecosys-**

tem simulation models with management-oriented models.

Overview of Key Scientific Issues

A critical issue in this priority research program involves developing techniques appropriate for assessing long-term sociological and economic impacts of future climate changes on multiple resource values in forests and related ecosystems. To be useful for such purposes, ecosystem models must be interfaced with socioeconomic or management-oriented models. Emerging quantitative techniques in the fields of artificial intelligence, expert systems, control systems theory, and environmental risk analysis provide potential means of interfacing ecosystem and management models. Further development of such quantitative techniques and the coupling of these techniques to ecosystem models are important goals of this initiative.

Example Research Areas:

(1) Develop methods of interfacing models of forests and related natural resource ecosystems with management-oriented models.

(2) Develop and adapt economic and environmental risk analysis methods for assessing impacts of future climate change on multiple forest resource values.

EXPECTED OUTPUTS

The expected outputs of this priority research program are designed to answer specific resource management and protection questions. Results from each of the research concerns listed in the previous sections will provide the scientific knowledge required to address strategic planning under a changed physical and chemical climate. New information will enable resource managers to do the following:

- Determine the changes in species distribution and forest composition resulting from air pollution and climate change effects;
- Predict growth and yield of commercial tree species, and as a result, future timber supply under a changing physical and chemical climate;
- Predict the quality of forest products and therefore their economic value under a changed climate;
- Predict changes in habitat and carrying capacity of rangeland for game, non-game, and managed animals as a result of climate change;
- Predict future water supply and quality in a changed physical and chemical climate;
- Predict changes in sediment load in water courses resulting from climate change;
- Predict changes in habitat for endangered species as a result of climate change;
- Predict changes in recreational opportunities, particularly in wilderness areas as a result of climate change;
- Predict the changes in fire frequency and severity and therefore be able to estimate the future protection required; and
- Predict the changes in severity and intensity of insect and disease outbreaks resulting from climate change.

RESEARCH ELEMENT CATEGORIES

The rationale for assigning categories for the research elements is based upon the workshop participants' evaluation of the lack of current technical information and need for additional information. The following category descriptions were developed by the group and used to assign categories to the research elements:

First - Keystone areas which represent fundamental research requirements for basic inputs to the science and which cut across the forest/atmosphere interaction issue. These research elements are necessary to complete the research of the second and third categories.

Second - Still basic research, but building upon previous efforts and available data, building to larger spatial scales, bigger picture of magnitude and extent.

Third - More specific research that rests on the building blocks of previous research, i.e., focusing on fisheries, wildlife, fires, etc. This work is likely to be more regional in scope, and differ in category at each Station.

USFS Research Categories

First - The three first category elements involve research that addresses USFS mission statements and basic information needs. The issues included apply across the entire system rather than according to regional priorities.

 # 1. *Energy, Carbon, Water, and Nutrient Cycling* **-** Determine the simultaneous responses of energy, carbon, water, and nutrient cycles with altered physical and chemical atmospheric conditions.

Rationale: This research element is very inclusive and focuses on producing basic information that is relevant to other problems. This research is an essential precursor to model inputs. The capability to do this research exists within the USFS and the value of the outputs is considered extremely high. Relevant research that provides a base upon which to build is ongoing at all Stations. This element involves intrinsic process-level research that is driven

by the science needs. Because little of this work has been done in the past, the needs are extensive. Finally, the research areas encompassed by this element are perceived to be difficult issues for which the USFS is uniquely qualified and which fit directly into the basic mission and responsibilities of the Service.

#13. *Long-Term Ecosystem Monitoring* - Institute and utilize long-term ecosystem monitoring, particularly using existing Experimental Forests, Experimental Rangelands, and Research Natural Areas to:

(a) determine long-term trends in forest, range and related ecosystems;

(b) identify critical variables necessary to assess ecosystems response to climate changes, and develop methodologies to monitor these variables on a wide basis, including monitoring within Forest Plans; and

(c) identify ecological, physiological, and/or morphological characteristics that can serve as indicators of chemical and/or physical environmental changes.

Rationale: This research directly addresses the following basic questions: What changes are occurring in forests and related ecosystems? What is the magnitude and extent of changes? A reasonable amount of previous effort in the area exists in other long-term USFS programs, including FRP, FIA, and FPM. The USFS has the capability to perform the work and is the appropriate agency to do so cost-effectively. This work has strong links scientifically to Elements 1, 2, 14, and 15. The output from this type of program directly supports decisionmaking; specifically, it can determine the relevancy of funding for fulfilling the greatest needs. This work falls under the highest priority largely because the PRP does not focus on isolated events but rather long-term changes in process such as cycling and other subtle changes over time. An adequate perspective on disturbance can only be achieved through long-term monitoring.

#14. *Ecosystem Management Models* - Develop and/or improve ecosystem models relevant to managing forests and related ecosystems.

Rationale: Modeling efforts provide a framework for asking and answering research questions more cost-efficiently and effectively. The capability exists within the USFS to develop and use these scientifically valid methods which are directly linked to Elements 1 and 13. This work provides research guidance and supports management decisions. The value is very high given that some questions cannot be answered through any other method.

Second - The three second category elements include research that addresses the current issues of concern more specifically but still focuses on basic research questions.

 # 2. *Species Life Histories and Distributions and Community Composition* - Develop methods to predict changes in species life histories and distributions and community compositions resulting from global climate change.

 # 3. *Water Yields, Erosion, and Sedimentation* - Develop methods to predict changes in water yields, erosion, and sedimentation in forest and rangeland resulting from global climate change.

#12. *Changes in Forest Area* - Determine effects of large changes in forest area (including fire) on energy, carbon, oxygen, water budgets and on composition of the atmosphere.

Third - The remaining third category elements focus on specific ecosystem effects and additional research support activities. These elements involve a more regional and station-level perspective.

 # 4. *Fire Severity and Occurrence* - Develop methods to predict changes in fire severity and occurrence resulting from global climate change.

 # 5. *Aquatic Ecosystems and Fisheries* - Determine the sensitivity of aquatic ecosystems and fisheries to changes in the physical and chemical environment.

 # 6. *Domestic and Wildlife Species* - Determine the sensitivity to and impact on domestic and wildlife species to changes in the physical environment and climate change.

 # 7. *Microbes, Plant Pathogens, and Insects* - Determine the sensitivity to and impact on microbe populations and microbe-produced products, plant pathogens, and insects to changes in the physical and chemical atmosphere.

 # 8. *Quantity and Quality of Wood* - Determine the effects of altered physical and chemical climate on the quantity and quality of wood.

 # 9. *Mass, Energy, and Momentum Transfer* - Develop an understanding of mass, energy, and momentum transfer between forests and the atmosphere.

#10. *Emissions of Forests and Forest Fires* - Refine estimates and mechanisms of emissions from forests and related ecosystems.

#11. Transport and dispersion of forest pollutants improve understanding of transparent and dispersion of pollutants associated with prescribed fire and wildfire.

#15. *Spatial and Temporal Scale Interfaces* - Develop techniques to improve interfaces between models at differing spatial sites and temporal scales.

#16. *Simulation and Management Model Interfaces* - Develop methods of interfacing ecosystem simulation models with management-oriented models.

PROGRAM PLANNING AND MANAGEMENT

General Program Goals

The current goals of the FAI-PRP are consistent with the historical and current mission of the USDA Forest Service. Much of the research planned or anticipated builds upon continuing efforts and can be designed to complement existing priorities at the station level. These general goals provide a framework to guide program planning and management objectives:

1. *Provide long-term technical input to policy questions* - At present, adequate technical information is not available to support sound policy decisions. In areas where some information is available, often the level of information is not sufficient for decision makers needs. In general, providers of the technical information must be made aware of how these information needs differ from their own requirement. A scientist thinks in terms of global solution, range of ouputs act, while a policy maker thinks in terms of regional solutions, risks etc. A corresponding list is:

Science	vs	**Policy**
Global		Regional
Outcomes		Risks
Means		Extremes
Cycles		Rates
Trends		Thresholds

The information needs for both components are similar but the levels of uncertainty and the timelines for producing the information may be very different. Thus, although scientists generally produce information at the level appropriate for state of the science, e.g., global, policy decisions are generally made at a regional level. The scientists may focus on the actual outcome and the overall average occurrence -- decision maker usually must know the potential risks of extremes, regardless of their likelihood. Similarly, policy decisions are often based on rates and perceived thresholds rather than trends and cycles.

2. *Maintain productivity of USFS commercial forest lands and wildlands* - An adequate information base and modeling tools are needed to manage U.S. forest resources appropriately in the near and far future.

3. *Provide international forestry leadership in addressing forest/atmosphere interaction problems* - The USFS is uniquely qualified, by experience and goals, to adapt its ongoing programs and research facilities to address this issue.

4. *Determine the nature (risks) and magnitude (thresholds) of climate-induced changes* - Much more extensive information, both basic and specialized, is needed on the feedback (interaction) between biosphere and atmosphere.

5. *Provide methods for detection of changes in forests and determination of causality* - Given the value and diversity of U.S. forest resources, more information is needed to allow some degree of "early warning" of changes so that appropriate management steps can be taken.

6. *Develop information base to allow evaluation of future options* - In order to continue protecting and maintaining forest ecosystems in an atmospheric environment that is becoming increasingly complex, forest managers must begin to develop broad based ecosystem understanding of interface processes.

7. *Provide information for forest and related lands management plans* - One of the ultimate goals of the USFS is to manage forests and related ecosystems for increased productivity while maintaining their basic structure and function. More information on the changing environment is essential to devising management plans for the future.

8. *Determine the important climatic variables in forests and related ecosystems* - Although some basic information is available, more detailed, mechanistic studies must be undertaken to determine the forest/atmosphere interactions that will most greatly affect and mold future forest ecosystems.

Program Budget

Budget development for the priority research program will follow the USFS research budget process. Only research recommended by the Stations will be included within the program. The process began with the FY 1988 budget presentations to the Office of Management and Budget (OMB) and Congress. It will continue in the FY 1989 President's budget, and will be accelerated in the FY 1990 budget documents that are currently being prepared.

The primary objective is to provide a smooth transition from the FRP to the FAI-PRP and prevent disruption of continuing research work. Table 1 presents an approximate budget given the target levels using the categories of the current FRP. This budget table assumes the following:

(1) About $13 million will be spent in this area of research in FY 1990, before any Congressional add-ons or initiatives from a new Administration are considered.

(2) The $13 million figure will be the minimum for future yearly budgets.

(3) Two additional increments will occur - i) an additional $8 million (for a total of $21 million) should be planned to meet probable Congressional and OMB interest if the National budget remains moderately healthy during the tenure of the next Administration and Congress; and ii) another increment of $9 million (for a program total of $30 million) should be planned for full program realization under RPA.

Incremental increases above the base $13 million reflect the priorities listed in the previous section. While the base funding includes elements from all three research categories, the budget strategy emphasizes increased basic science (category 1) and focused resource and protection elements (category 3) with category 2 elements increased at a uniform budget percentage. The base funding would provide for limited long-term monitoring, fundamental research on carbon, water, and nutrient cycling, and development of empirical models and prediction systems. The first incremental increase, to a funding level of $21 million, would (1) expand the long-term monitoring both in scope and geographic extent, (2) initiate research on species distribution and composition, (3) initiate research on water yield and sedimentation in a changed climate, and (4) initiate research on the effects of large-scale changes in forested area. A fully funded program ($30 million) would further increase the long-term monitoring, strengthen and broaden the fundamental research on carbon, water, and nutrient cycling, species distribution, large aerial changes in forest cover, and water yield and sedimentation. The full funding would also initiate research on linking the basic technical information to the management models for better prediction and on climate change effects on fire, aquatic ecosystems, domestic and wildlife species, and insects and pathogens.

Table 1. *Approximate Summary Budget* - in million $s.(Scientist year = $170K)

Category	Base Funding	Mid-Level Funding	Full Funding
Monitoring (Element 13)	2.5	4.0	5.5
Scientist Years	14.7	23.5	32.4
Chemical climate (Elements 1,2,12)	6.0	9.0	12.0
Scientist Years	35.3	52.9	70.5
Water Yield (Element 3)	1.0	1.5	2.0
Scientist Years	5.9	8.8	11.8
Modeling (Elements 14,15,16)	1.0	2.0	3.0
Scientist Years	5.9	11.8	17.6
Specific impacts (Elements 4,5,6,7,8,9,10)	2.5	4.5	7.5
Scientist Years	14.7	26.5	44.1
TOTALS	13.0 (level)	21.0 (+8.0)	30.0 (+9.0)
Scientist Years	76.5	123.5 (+47.0)	176.4 (+99.9)

Human Resource Needs

Over the next five years, the USFS will experience about 50 percent turnover in personnel, and about 70 percent turnover during the next ten years. Given the nature and duration of the FAI-PRP, the USFS should be anticipating the future and taking appropriate steps to ensure a sufficient workforce of well-qualified individuals. Specifically, the agency should be working closely with schools and educators to keep them informed about the predicted employment opportunities for the various areas within forestry and in related disciplines.

Although detailed information on currently available employees, turnover and recruiting, and coverage by discipline was not discussed, the following areas were recommended for new hiring given the anticipated research program:

Administration/Management
Biogeochemical processes
Econometry
Ecosystem modeling
Forest hydrology
Geography
Landscape ecology
Chemical engineering
Computer analyst
Limnology
Nutrient cycling
Plant physiology
Remote sensing
Soil science

Atmospheric science
Biogeography
Ecophysiology
Forest ecology
Geochemistry
Ground and surface water hydrology
Community ecology
Chemistry
Liberal Arts
Mathematics
Plant pathology
Population ecology
Statistics

MANAGEMENT ISSUES AND APPROACHES

Changing demands upon forests and rangelands require flexibility in research programming and organization to meet current and anticipated needs for knowledge and methodology. At the same time, Department and Forest Service policies require (1) planned and approved research programs and (2) sound development of research organization and facilities.

Planned Research Programs

Planned project research is based upon periodic reviews and analyses that consider the following:

- Conditions and trends in forest and range management and utilization, nationally and regionally;
- The values placed on economic strength and social well-being in the urban, suburban, and rural environments in relation to the resource problem;
- The environmental impacts of alternative strategies for managing forest and rangelands for a multiplicity of uses and outputs;
- The natural ecosystems and the need to develop interdisciplinary research capabilities to understand better the interrelationship of phenomena in the system;
- Past research and the current status of knowledge and practice in the Federal sector, the academic sector, in the private and public research organizations, and in international groups and organizations fostering forestry research; and
- Current and future needs for technical information by managers and users of forest and range in both private and public ownership;

Adapted from Forest Service Manual, March 1972, Amendment no. 21.

Development of Organization and Facilities

The timber, water, forage, wildlife, and recreation resources of forest lands and rangelands are interrelated. Furthermore, the management, protection, utilization, and economics of these resources often are interdependent. The sound development of organization and facilities for coordinated research on these multiple resources for a variety of outputs requires recognition of two seemingly conflicting facts: (1) the vast expanse and diversity of the Nation's forest and rangelands, and the social and economic atmosphere and terms affecting the use and management of these lands and (2) the essential unity of forest and range research.

In "Research in the United States Forest Service, A Study in Objectives" (S. Doc. 12, 1933, A National Plan for American Forestry), Earle H. Clapp, the first chief of the Research Branch, provided excellent policy guides for the development of research organization and facilities. These and other policy guides follow:

- Maintain the research organization as a separate entity in the Forest Service. This parallels Department policy established in 1915, definitely segregating regulatory, extension, and research activities within each bureau.
- Consolidate all research programs under the Deputy Chief for Research who has responsibility for the technical programs.
- Provide an organization that is responsive to changing needs and that fully relates to solving the problems of economic development and the maintenance and enhancement of environmental quality in rural, suburban, and urban environments.
- Maintain effective relationships between Research and National Forest Resource Management, State and Private Forestry, and cooperating forestry organizations and individuals. Under this policy, Research is responsible for determining its own techniques and for administering its own program, but must take into account the needs of the users.

- Cooperate with other public and private agencies and individuals interested in forest and range research.

- Develop and maintain effective field units for coordinated attack on forest and range problems of regional and national importance.

- Recruit, train, maintain, and advance a staff of competent scientists and of experienced technical and clerical employees dedicated to public service.

- Provide a suitable research environment, including: (1) the stimulation afforded by frequent consultations with other scientists, (2) adequate facilities for good research, such as laboratories, libraries, offices, experimental areas and equipment, and (3) insofar as possible, conservation of scientists time for research activity.

- Maintain effective decentralized supervision with clearcut accountability, organized under a system which maintains scientific freedom of inquiry under the team approach and provides for pioneering research in broadly basic fields of inquiry.

Such a decentralized management, where the Deputy Chief for Research provides national coordination and planning and the Station Directors are responsible for administering the research programs, allows for a responsive research organization that guarantees local research needs are met in a timely fashion.

Because the FAI-PRP is a national program and contains international activities, particular attention must be focused on coordination activities.

Management of the research program can be assisted through several committees formed for different purposes.

(a) *Advisory Committee* - An advisory committee is particularly useful to promote interaction between different agencies of government and outside groups with same or similar needs for information on forest effects, but who do not have authority to participate directly in program decisionmaking. An advisory committee can integrate Federal-State interests, policy-science issues, government special interest group concerns, and/or national-international interests. The primary responsibility of the advisory committee is to review program outputs (including planning documents) and to make recommendations to the program management (see steering committee below). Although such recommendations are not binding on a government program, they provide a forum for outside participation and allow a much wider range of expertise and views to be included.

(b) *Steering Committee* - A steering committee, in contrast to an advisory committee, has some management control over the research at the program level.
The steering committee is responsible for the basic planning and strategy of the research program from the earliest stages, essentially steps 1-3 above.

The members of this committee should be high-level program managers of the various related research groups. These members must have working knowledge of the issues and, with additional advisory input, can direct the program. The research areas to be represented on this steering committee include forest scientists, atmospheric scientists and air quality specialists, environmental scientists, and possibly policy makers.

The functions of the steering committee could be:

(1) to promote integration between the related research areas and organizational units;

(2) to direct the overall scope and focus of the research program; and

(3) to provide oversight for the program as a whole through ongoing interaction, i.e., identify gaps and deficiencies.

The primary responsibilities of the steering committee could be:

(1) to determine the overall objectives of the research program and periodically reevaluate them;

(2) to propose, evaluate, and approve the assessment questions which will drive the research program; and

(3) to direct the program, based on the research questions, in a continuous and ongoing manner through periodic, thorough meetings that review program status, accomplishments, and future goals.

National and International Research Integration and Cooperation

Although this approach is an essential component of all of the above described approaches, it deserves special mention. International and government-wide interaction is more likely to increase information exchange between nations, and between agencies of the Federal government. The effects of atmospheric change and pollution is an issue of concern across North America and Europe. Transboundary agreements on air pollution will only be promoted by closer integration of international research objectives and results. The most effective means of promoting interaction and integration are through participation in national and international scientific meetings and technical reviews. Such forums stimulate exchanges of information and promote the acceptance of final research results.

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APPENDIX A

USDA Forest Service
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Forest/Atmosphere Interaction Priority Research Program

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APPENDIX B

Program Elements Identified at Reston Workshop for the Forest/Atmosphere Interaction Priority Research Program

The Forest Service priority research program on Forest Productivity and Health in a Changing Atmospheric Environment is based on the concerns about the future state of our forests in a changing physical and chemical climate. The program will emphasize fundamental science and will be long term. It will address multiple pollutants and atmospheric change and variability on forest ecosystems. The program consists of four broad areas:

- Process of atmospheric effects on forests;
- Effects of forest management on the atmosphere;
- Long-term monitoring of effects; and
- Development of management options based on the research results obtained in the three previous areas.

Specific Research Problems Identified at Reston Workshop

PROCESSES OF ATMOSPHERIC EFFECTS ON FORESTS

The initial need is to determine what effects the changed atmospheric chemistry, temperatures, and increased variability of the physical and chemical climate have on ecosystems.

1. Determine the simultaneous responses of carbon, water, and nutrient cycles at altered physical and chemical atmospheric conditions.

2. Refine understanding of the processes by which the atmosphere transports energy and materials within forest canopies, and how these materials are utilized in the photosynthesis process.

3. Develop methods to predict changes in species compositions and distributions resulting from global climate change.

4. Develop methods to predict changes in water yields from forest and rangeland resulting from global climate change.

5. Develop methods to predict changes in fire severity resulting from global climate change.

6. Determine the sensitivity of aquatic ecosystems and fisheries to changes in the physical and chemical atmosphere.

7. Determine the sensitivity to and impact on wildlife species to changes in the physical environment and climate change.

8. Determine the sensitivity to and impact on microbe populations and microbe produced products to changes in the physical and chemical atmosphere.

9. Determine the sensitivity to and impact on plant pathogens in a changed physical and chemical atmosphere.

10. Determine the sensitivity to and impact on insects in a changed physical and chemical atmosphere.

11. Determine the effects of altered climate and chemical composition on the quality and quantity of wood.

EFFECTS OF FOREST MANAGEMENT ON THE ATMOSPHERE

A second area of needed research is in the general area of determining what effects human activity in the forests will have on the climate.

12. Refine estimates and mechanisms of emissions from prescribed fire and wildfire.

13. Develop understanding of transport, dispersal, and removal of pollutants from prescribed fire and wildfire.

14. Determine effects of large area forest removal on carbon, oxygen, and water budgets and relative composition of the atmosphere.

MONITORING THE PROBLEM

A third need is to develop an appropriate monitoring program which would relate the improved understanding of the processes in the two previous sections to the methods of quantitatively evaluating the atmospheric change and variability on management strategies.

15. Support long-term measurements of forest, range, and related ecosystems, particularly on Experimental Forests and Rangeland and on Research Natural areas.

16. Identify critical variables necessary to assess ecosystem response to climate changes, and develop methodologies to monitor these variables on a wide basis, including monitoring within Forest Plans.

17. Identify ecological, physiological, and/or morphological characteristics that can serve as indicators of chemical and/or physical environmental changes.

DEVELOP MANAGEMENT OPTIONS

The final area of research needs is in developing the methodologies to quantitatively use the knowledge of the processes and the database from the monitoring activities in developing management strategies.

18. Develop and verify physiological model(s) to determine the carbon, water, and other chemical budgets in forest stands.

19. Improve biophysical aspects of plant growth model(s), and incorporate physical and chemical environmental changes in these model(s).

20. Develop and/or improve models of water quantity which incorporate physical and chemical environmental changes.

21. Develop and/or improve physiologically-based stand process models which are linked to growth and yield models.

22. Develop models on impact of physical and chemical climate variations on wildlife and fish.

23. Develop techniques to improve interfaces between models at differing spatial and temporal scales.

24. Develop economic and risk analysis techniques of projected physical and chemical climate on ecosystems.

APPENDIX C

CURRENT FOREST SERVICE RESEARCH ACTIVITIES RELATED TO FOREST PRODUCTIVITY AND HEALTH IN A CHANGING ATMOSPHERIC ENVIRONMENT

The current Forest Service Research program related to this initiative is conducted at eight Experiment Stations. A brief summary of these research activities are included below. These research problems cover the broad areas of forest productivity/sensitivity, water quality, synergistic effects of pollutants and insect and disease, effects on soils, effects on fauna, monitoring techniques and meteorological modeling.

Intermountain Forest and Range Experiment Station

Research Work Unit (RWU)-INT-4302, Soil and Water Management in the Northern Rocky Mountains. The research problem in this unit is chemical transport and atmospheric deposition effects on forested watersheds.

RWU-INT-4151, Quantitative Analysis. This unit is developing a framework for linking vegetation changes to climate changes.

North Central Forest Experiment Station

RWU-NC-4301, Water Quality Management in Forests of the Western Great Lakes Region. The research problem in this unit is to increase the basic knowledge of the impacts of acidic deposition on the soils and waters of the Western Great Lakes.

RWU-NC-4502, Canker, Foliar and Root Diseases of Nurseries, Forests, Plantations, and Christmas Tree Plantations. One research problem in this project is on the role of acidic deposition immortality and decline of oaks and hickories.

RWU-NC-4851, Multiple Use Evaluation and Modeling of Forest Ecosystems in the North Central Region. A problem that this unit is working on is the relationship of Lake States forest growth to the level of acidic deposition and to microclimate variables.

Northeastern Forest Experiment Station

RWU-NE-4103, The Role of Environmental Stress on Tree Growth and Development. This unit is working on a problem related to this initiative, physiological effects of site acidification on tree growth and development.

RWU-NE-4301, Water Resources Protection in Central Appalachian Forests. The research problem in this unit is the impact of atmospheric deposition on the soil and water resources of Appalachian forests.

RWU-NE-4452, Acid Rain Program - Eastern Hardwood Research Cooperative. This program supports extensive extramural research on effects of atmospheric deposition on eastern hardwood forests.

RWU-NE-4351, Physical Amenities and Water Supplied by Urban and Community Forests and Municipal Watershed Environments. One of the research problems in this unit is on the impact of atmospheric deposition and land use practices on water quality in municipal watersheds.

RWU-NE-4352, Impact of Forest Management and Acid Precipitation on Nutrients in Soils and Water. The research problem is to evaluate the combined effects of forest management practices and acid precipitation, and to operate the Hubbard Brook Experimental Forest as a Biosphere Reserve.

RWU-NE-4451, Acid Rain Program - Spruce Fir Research Cooperative. This program supports extensive extramural research on effects of atmospheric deposition on spruce-fir forests.

RWU-NE-4503, Effects of Atmospheric Deposition on Forests and Trees in the Eastern U.S. Two research problems within this unit are related to this initiative. First are the effects of atmospheric deposition on biochemical/physiological processes and ultrastructural changes and, second, effects of atmospheric deposition on forest trees in the eastern U.S.

RWU-NE-4505, Etiology and Epidemiology of Stress-Regulated Host-Pest Interactions. This unit is addressing the problem as to whether or not atmospheric deposition predisposes trees to attack by disease and insect pests.

RWU-NE-4510, Physiological and Biochemical Mechanism of Tree Response to Injury and Infection. A research problem in this unit is to conduct additional research to determine how air pollution alters wood quality.

Pacific Northwest Forest and Range Experiment Station

RWU-PNW-4101, Reforestation Systems in the Pacific Northwest. This unit has two research problems related to forest/atmosphere interactions. One is on vegetation management and planting stock for reforesting harsh sites in southwestern Oregon and the other is on quantitative ecological information on the nature and intensity of vegetation competition.

RWU-PNW-4103, Biology and Silviculture of Forests of the Douglas-fir Region. This unit has three problems of relevance here: improved understanding of influences of growing stock manipulation on forest production, nitrogen-fixation species of nitrogen-fixing plants in northwest forests, and need for better quantitative assessment and prediction of douglas-fir stand development.

RWU-PNW-4151, Ecological Basis for Management of Northwest Coniferous Forests. This unit's mission has concentrated on the response of the ecosystem to major stress - the Mount St. Helens' eruption.

RWU-PNW-4351, Ecology and Management of Taiga and Associated Systems in Interior Alaska. This unit has two problems related to basic ecosystem ecology, nutrient cycling, and forest productivity in taiga forests following fire and floodplain deposition. It is also heavily involved in the NSF Long-Term Ecological Research (LTER) program in Bonanza Creek Experimental Forest and in attempts to establish long-term monitoring at the tundra-taiga ecotone in the Noatak Biosphere Reserve in northwestern Alaska.

RWU-PNW-4352, Ecology and Management of Forests and Associated Ecosystems in Coastal Alaska. This unit is working on the problem of effects on timber productivity of harvest, vegetation, soil, stocking, and fertilization.

RWU-PNW-4354, Soil Stability and Water Quality of Managed Forests of Eastern Oregon and Washington. One of the problems this unit is working on is response of conifer seedlings to environmental factors on newly harvested sites. A second problem is to determine factors that influence site productivity and successional trends.

RWU-PNW-4401, Fire and Air Resource Management. This unit has three problems of relevance here: methods to predict and prescribe the immediate effects of fire in new situations are needed; characterization of emissions from prescribed fire to the precision needed for receptor modeling and source strength predictions is lacking; and evaluation of techniques and strategies to reduce air pollution from prescribed fire is needed.

RWU-PNW-4505, Symbiosis and Diseases in Western Ecosystems. Two relevant problems are identified in this unit: quantifying, predicting, and controlling damage from laminated root rot, and growth and yield losses caused by dwarf mistletoe.

RWU-PNW-4702, Improved Utilization of Western Forest Biomass for Fiber and Energy. This unit is working on the problem of effects of biomass removal and site preparation on nutrient capital and site productivity.

Pacific Southwest Forest and Range Experiment Station

RWU-PSW-4301, Environmental Hydrology of the California Snow Zone. This unit has identified that better information is needed on Sierra Nevada snowpack chemistry and the role of snowpack in the deposition of atmospheric pollutants in the California snow zone.

RWU-PSW-4352, Ecology and Fire Effects in Mediterranean Ecosystems. One of the problems being investigated by this unit is based on a lack of information of the impacts of fire and air pollution on nutrient and chemical cycling in southern California chaparral ecosystems.

RWU-PSW-4401, Meteorology for Fire Severity Forecasting. This unit is working on the problem of increasing the knowledge of the magnitude, duration, and spatial variations of fire severity through use of global circulation models. It is also working on methods to design weather station networks. This latter problem is important in any monitoring activity.

RWU-PSW-4451, Atmospheric Deposition Effects on Montane Forests in the Western U.S. This unit has determined that it is necessary to find out what changes in forest productivity are being caused by increased levels of atmospheric deposition to montane forests.

Rocky Mountain Forest and Range Experiment Station

RWU-RM-4151, Multi-resource Management of Central and Southern Rocky Mountain Forest and Woodlands. This unit is working on two problems of relevance to this initiative: (1) Forest management decisionmaking for coniferous and aspen forests is difficult because multi-resource consequences of stand management activities cannot be adequately predicted; and (2) Ability to quantitatively predict establishment, structure, growth and yield of forest and woodland vegetation, including impacts of forest pests, is inadequate to achieve desired management objectives.

RWU-RM-4452, Atmospheric Deposition in Natural Ecosystems of the Western United States. Two problems are under investigation by this unit: processes by which atmospheric chemicals are incorporated into snow packs and subsequently transferred, transformed, and physically distributed are poorly understood; and knowledge of the atmospheric deposition on productivity of salmonid habitat and sensitive components of alpine and subalpine terrestrial ecosystems in the western United States is lacking.

Southeastern Forest Experiment Station

RWU-SE-4102, Forest Soil Productivity in the Southeast. This unit is working on the effects of airborne chemicals on tree growth and on chemical and biological properties of the soil.

RWU-SE-4351, Water, Soil, and Aquatic Responses to Management of Southern Appalachian-Piedmont Forests. This unit is working on three problems: atmospheric deposition effects on the spruce-fir ecosystem in the southern Appalachians; effects of alternative management practices on water yield and quality; and long-term hydrologic and ecological effects on forested watersheds.

RWU-SE-4403, Forest Meteorology and Eastern Fire Management. One problem that this unit is currently working on is methods to specify fuel moisture for locations which fall between observing stations. This work on data extrapolation is an important aspect of any monitoring activity.

RWU-SE-4802, Atmospheric Deposition Effects on Natural Vegetation. This Research and Development Program has as a problem area, the Atmospheric Deposition National Vegetation Survey.

RWU-SE-4852, Effects of Atmospheric Deposition on the Health and Productivity of Southern Commercial Forests. One problem topic in this Research and Development Program is the effects of airborne pollutants on growth and yield of southern commercial forests.

Southern Forest Experiment Station

RWU-SO-4351, Hydrologic Evaluation of Forest Management Alternatives for Southern Coastal Plain Pinery and Ozark-Ouachita Highlands. Two problems are under investigation by this unit: effects of harvesting and regeneration alternatives on water yield and distribution, water quality and site productivity, and a monitoring activity to provide fundamental data needed for the Ozark-Ouachita Highlands regarding effects of silvicultural practices on water quality, yield, soil losses, site productivity regeneration, and growth response.

RWU-SO-4101, Silviculture of Southern Pines in West Gulf Coastal Plain. Mission is to provide the fundamental information necessary to develop improved methods of artificial regeneration for the major southern pines and determine relationships of establishment and growth to site, stand factors, and cultural treatments, including intensive soil and stand management practices to maximize growth and quality.

RWU-SO-4105, Control of Undesirable Vegetation in Southern Pine Forests. Mission is to develop effective, ecologically sound, and economically attractive methods of controlling unwanted vegetation in southern forests.

RWU-SO-4107, Institute for Quantitative Studies. Mission is to develop quantitative techniques and systems for predicting growth and yield of important mid-South types.

RWU-SO-4108, Genetics of Southern Pines. Mission is to determine the extent of genotypic variation in commercially important southern pines and develop efficient procedures for their genetic improvement.

RWU-SO-4151, Tropical American Forest Management. Mission is to strengthen the basis for sound forest management by developing cultural practices that increase productivity of tropical and subtropical forest ecosystems. Additionally, cooperatively with State and Private Forestry and others, dcntinue to serve as center for training tropical forest land managers and researchers to understand forestry problems of regional priority.

RWU-SO-4501, Pest Management Strategies for the Southern Pine Beetle. Mission is to provide knowledge of population dynamics and interactions of southern pine bark beetles, host trees, and stands to improve forest pest management.

RWU-SO-4503, Diseases of Southern Pines. Mission is to develop alternative methods to minimize losses from fusiform rust in slash pine planting and to assess gains resulting from implementation of control strategies.

RWU-SO-4504, Southern Hardwood Insects and Diseases. Mission is to develop pest management strategies and guidelines necessary to minimize insect and disease losses in intensive culture and multi-use natural stands of southern hardwoods.

RWU-SO-4801, Forest Inventory and Analysis of Mid-South States. Mission is to develop, analyze, and maintain renewable forest resources information for the mid-South States and Puerto Rico and conduct research to provide improved inventory and evaluation techniques.

APPENDIX D

RELATIONSHIP TO OTHER PROGRAMS

Although a broad range of research related to global climate has been underway since the early 1960s, recent scientific evidence has stimulated intensified research investigations into the rate and nature of climate changes due to human activities. A number of new or restructured programs are being developed at the national level by various agencies. The USFS program will complement these other efforts to allow optimal productivity from the resources made available and to avoid duplication of research. The precedent for successful interagency cooperation has been established within the forestry community through NAPAP and the FRP. In many respects, the FAI-PRP has greater potential because of this growth of interagency cooperation over the past decade and the maturity of the forest and atmospheric sciences involved, compared to the knowledge of the acidic deposition phenomenon ten years ago.

The first step of the USFS program will be to examine closely the existing USFS research activities and activities underway in other agencies and organizations to identify the crucial gaps that need to be filled regarding effects on forested ecosystems. The following provides a brief overview of the relevant programs that currently exist or are being developed.

Climate-related work in the United States is coordinated through the National Climate Program (NCP). The NCP was established by Congress in 1978 for the explicit purpose of providing a focus for federally sponsored research on climate change. The main components of the program are: (1) climate data and services, (2) climate modeling and prediction, and (3) climate change and environmental impacts. The National Climate Program Office (NCPO) has the statutory responsibility to coordinate climate research activities among federal agencies and with international organizations. Eight principal agencies participate in the program.

The National Academy of Sciences conducted/sponsored a review workshop on the initial accomplishments and future directions of the National Climate Program (NAS, 1986b). The review group recognized that although progress has been made in impacts research, this research area in particular needs strengthening. Specific topics on impacts were identified for additional study, including investigation of:

- relation of climate variability to water quality, optimization of water use efficiency under various climatic conditions, and the impact of potential long-term climatic change on water supply systems;
- drought and the contribution of human activity in causing climate change, with special emphasis on Africa;
- impact of climate change (from Carbon Dioxide and other radiatively active trace gases) on long-term decisions such as water resource development/utilization and energy planning.

The NAS group also identified the need for the coordination and verification of climate impact models. The group's final recommendation was that the appropriate agencies make investments that create a lasting national assessment capability in order to carry out their missions. The NCPO was suggested to serve as a catalyst for assessments and could play an important role in coordinating future research on climate impacts.

The NCPO's current five-year plan covers FY 1988-92 and broadly identifies general research roles for each agency within the total national program (NCPO, 1987). However, the plan does not address the specific needs of an expanded applied climate impacts research effort. For example, in the area of climatic change and environmental impacts, the USFS could function as the lead agency in coordinating work on monitoring of sensitive forested ecosystems to provide input to integrated regional analyses of climate impacts. The USFS also could contribute to the development of response strategies as part of their responsibility for the management and protection of these resources. Currently, no agency is listed as having primary responsibility in these particular areas.

The FAI-PRP will be designed to fill gaps in the current National Climate Program. In order to build a program that complements the ongoing activities, the USFS is particularly interested in those agencies conducting effects-oriented work, such as the National Science Foundation, EPA, and the U.S. Geological Survey.

National-Level Programs

National Science Foundation (NSF)

NSF is the principal source of support for independent investigations in the impacts area of the National Climate Program. There are four major components to NSF's climate-related research program: (1) The emphasis of the Climate Dynamics Program ($8.5 million) is on analysis of data, modeling, and paleoclimatic and contemporary research; diagnostic work; and tool development studies for impact assessments; (2) The Atmospheric Chemistry Program ($8.5 million) sponsors atmospheric studies and socio-economic impact activities at the National Center for Atmospheric Research (NCAR); (3) Under the Ecology Program ($9 million), NSF is investigating the use of ecotones to study sensitivity to climatic change, which is an approach of extreme interest to the USFS; and (4) The primary effort under NSF's Ecosystem Program ($18-19 million) is the Long-Term Ecological Research (LTER) Program, with 15 sites nationwide. Basic research is underway on the landscape and regional scale.

NSF initiated a new program on Global Geosciences in 1986 to investigate major cause-and-effect relationships within and between the climate system, biogeochemical cycles and tectonic activity, all operating within the atmosphere, oceans, biosphere, and solid Earth. A major component of the program focuses on global ecosystem dynamics. The sources and sinks of natural and man-made materials are being studied to understand the processes controlling the Earth's environment. Research is directed at biosphere processes such as the influence of climate and anthropogenic factors on ecosystems, removal processes and biological effects of atmospheric constituents, scale-dependent interactions of the biosphere and atmosphere, and the role of tropical forests and other habitats in biological diversity. The National Aeronautics and Space Administration (NASA) and the National Oceanic and Atmospheric Administration (NOAA) were named as FY 1987 and FY 1988 participants in these geosphere research efforts.

National Aeronautics and Space Administration (NASA)

In 1986, NASA announced an Earth System Science program "to obtain a scientific understanding of the entire earth system on a global scale by describing how its component parts and their interactions have evolved, how they function, and how they may be expected to continue to evolve on all timescales." The program includes geology, physical climate, and biogeochemical cycles, but little emphasis on biological processes. The three major objectives of the program are very reliant on space technologies: long-term continuous observations, advanced information processing systems, and conceptual and numerical models. The major cooperators in this effort are NOAA and NSF.

National Oceanic and Atmospheric Administration (NOAA)

NOAA is responsible for gathering, archiving, and disseminating climate and weather data for the National Climate Program, including data from impacts studies. NOAA also is the lead agency for long-and extended-range climate prediction, which is an important component needed to support the effects studies proposed by the USFS. NOAA is the lead agency for contact with the World Climate Program (WCP) described below. The National Environmental Satellite, Data and Information Service (NESDIS) is a branch of NOAA that is responsible for satellite programs, and the National Climate Center is responsible for processing and archiving climatological data and for climate analysis and assessment. In 1986, NOAA developed the Global Tropospheric Chemistry and Global Ocean Flux Program to complement the NASA and NSF programs described above.

U.S. Department of Energy (DOE)

DOE's Carbon Dioxide Research Division has supported research since 1978 on the changes in atmospheric carbon dioxide; the global carbon cycle; the extent of subsequent changes in regional and global climate from increased Carbon Dioxide

enrichment on ponderosa pine, white oak and yellow poplar; the grassland, wetland, and tundra relationships of elevated Carbon Dioxide to drought and other climate variables; and the physiological responses of root and mycorrhizal systems to elevated Carbon Dioxide levels. In an annual inventory of related research, The Agricultural Research Service (ARS) reported $1.5 million and the USFS reported no related studies in FY 1986.

National Center for Atmospheric Research (NCAR)

NCAR was chartered by NSF in 1960 and is funded primarily by NSF for major research programs in atmospheric analysis and prediction, atmospheric chemistry, convective storms, high-altitude observatories, and scientific computing. Some of NCAR's research initiatives include the international Global Atmospheric Research Program (GARP), global climate models, turbulence and boundary-layer studies, super-computing techniques and applications, solar and coronal physics, remote sensing for atmospheric processes, and severe storms and meteorological events.

U.S. Environmental Protection Agency (EPA)

By congressional mandate, EPA's Office of Policy, Planning and Evaluation (OPPE) is developing two assessment reports on climate change: (1) health and environmental effects of climate change, and (2) policy options for stabilizing the atmosphere. The Effects report is particularly relevant to this area of the proposed EPA/Office of Research and Development research program. The report will describe the state of current knowledge on the impacts of climate change on agriculture, forests, wetlands, rivers, and lakes, and identify important gaps in the current research. ORD is working with OPPE to provide input and review of the report, which is due to Congress in December 1988.

EPA expects to play a major role domestically and internationally in research, risk assessment, monitoring, and policy analysis on effects of trace gases on global change. The proposed EPA program will develop an increased understanding of the significance of global climate change to EPA activities, and impacts of EPA activities on climate change. Four major areas have been identified: (1) a need for process-oriented research and subsequent model development, namely a trace gas model and its relationship to a general circulation model; (2) development of risk analysis and risk management procedures; (3) long-term monitoring of trace gases in remote regions, monitoring of ecological systems sensitive to climate change, and monitoring of emissions and human activities likely to alter trace gas concentrations; and (4) those issues which would impact policy, including the range of change possible without action, sources of uncertainty in the analysis, options and obstacles to reduce emissions, and relations between timing of action and costs. This $3.6 million per year program will be coordinated with the National Climate Program.

U.S. Department of Agriculture (USDA)

Through the Agriculture Research Service (ARS), USDA has conducted studies on the relationship between climate change and crop productivity, the indirect effects of climate on pests and pathogens, and the resistance of crops to atmospheric pollutants. Research related to forests and related ecosystems conducted within the USFS is described in the previous section.

U.S. Geological Survey (USGS)

Within the Department of the Interior, the USGS has the lead responsibility for research on climate change. The focus of this work is in two primary areas: water resources and paleoclimatic studies. Currently, USGS supports a $10-15 million program on the effects of climate change on water quantity and quality. The program, however, is composed of independent projects and does not include climate-oriented monitoring. USGS plans to build a more comprehensive program (about $20 million) specifically related to hydrology-climate interactions, and hopes to become a focal point for hydrology in the climate-change arena. While the major emphasis is in the water resources area, a small program (about $1 million) is underway using paleoclimatic studies to investigate climate change.

Much of the work being conducted by USGS is relevant to ecological effects, especially in the water resources area. With the USGS as the primary source of hydrologic data for the United States, new

programs should work closely with USGS to coordinate activities and exchange relevant data. USGS plans to perform impact studies on the water resources of the major hydrologic units of the United States, which will be of keen interest to the USFS.

American Association for the Advancement of Science (AAAS)

The AAAS Committee on Climate was established in 1977 and has focused on the role of climate, climatic variability, and climate change on society. The Committee has brought attention to the scientific questions and public policy implications by holding symposia at each AAAS annual meeting since 1979, sponsoring several international workshops, and supporting research planning efforts conducted by DOE's Carbon Dioxide Research Program.

International Programs

In addition to national-level activities, the involvement of other governments and multilateral organizations, such as World Meteorological Organization (WMO), United Nations Environment Programme (UNEP), and International Council of Scientific Unions (ICSU), is essential for planning and implementing research on a global scale. While such coordination already occurs through the National Climate Program Office, U.S. programs also should collaborate directly with other countries and international organizations conducting effects-related research, primarily through workshops, meetings, correspondence and data exchange. There are two major international programs that relate to the FAI-PRP: the World Climate Program and the International Geosphere-Biosphere Program (also called Global Change Program).

World Climate Program (WCP)

The WCP was formed in 1976 and is administered by the WMO. Participators in the WCP include UNEP, the International Oceanographic Commission, and the ICSU. The WCP and WMO are increasingly emphasizing the importance of better knowledge of global atmospheric-biospheric interactions. Data, Applications, Research, and Impact Studies are the four major components of the World Climate Program. The similar structure between WCP and the U.S. National Climate Program facilitates coordination and provides opportunities for sharing of resources. The United States participates in several projects conducted within the Research component of the WCP.

Under WCP's World Climate Impacts Program, there are three principal projects: (1) the Scientific Committee on Problems of the Environment (SCOPE) project on impact assessment methods, (2) the International Institute for Applied Systems Analysis (IIASA) project on climate impacts on cold and semi-arid agricultural margins, and (3) the International Meteorological Institute (IMI) project on Carbon Dioxide induced climate change, emphasizing effects on northern ecosystems. While overall results of these projects have been good, the NAS (1986b) found management of the Impacts program has been weak.

International Geosphere-Biosphere Program (IGBP)

In 1986, ICSU endorsed the establishment of a major interdisciplinary research program: the International Geosphere-Biosphere Program, commonly called the Global Change Program. The U.S. committee for this program is under the auspices of NAS. Their 1986 report (NAS, 1986a), "Global Change in the Geosphere-Biosphere: Initial Priorities for an IGBP," recommended a 10-year program. The objective of the program is "to describe and understand the interactive physical, chemical, and biological processes that regulate the Earth's unique environment for life, the changes that are occurring in this system, and the manner in which they are influenced by human activities." Preparatory work is underway now to develop implementation plans for the operational phase of the program, which is scheduled to begin in the early 1990s. The program will emphasize interactive processes that are not being addressed by other existing programs and will include studies on history of environmental change, global observations, global models, biosphere process research, and biogeochemical and hydrologic cycles. Topics suggested for early emphasis in the IGBP include studies on: (1) biogeochemical cycles, (2) soil dynamics and soil chemistry, (3) the ocean euphotic zone, and (4) variable solar input to the Earth. These first two areas, in particular, are relevant to FAI-PRP program. Several

U.S. agencies already have formulated research and observational programs to contribute to the IGBP:

NASA	-	Earth Systems Science Program;
NOAA	-	Climate and Global Change Program; and
NSF	-	Global Geosciences Program.

Other agencies that are developing program initiatives on global change include DOE, EPA and USGS.

In addition to the organizations involved in these two major programs, other international groups sponsor work on global climate change, including UNEP and the Organization for Economic Cooperation and Development (OECD). UNEP is initiating four regional impact studies using a variety of analytical methods including scenario development, historical analogues, and time-series impact analysis with remote sensing data. A similar program is being implemented on the analysis of climatic impacts on marine ecosystems, and coastal and adjacent marine-based social and economic systems.

The OECD Environment Committee is examining the potential role for OECD in the climate change issue. Initial plans focus on two streams of activities (OECD, 1987): (1) Environmental and socio-economic impacts of climate change. Proposed activities include reviewing existing impact assessment methods and related projects, conducting regional analyses, estimating socio-economic impacts, and developing response strategies, and (2) Energy and economic policy. Suggested projects include reviewing energy policies, assessing potential emissions of greenhouse gases, and reviewing institutional and financial arrangements.

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